(12) UK Patent Application (19) GB (11) 2 146 791 A

(43) Application published 24 Apr 1985

(21) Application No 8422399

(22) Date of filing 5 Sep 1984

(30) Priority data

(31)	(32)	(33)
58/170647	16 Sep 1983	JP
59/068648	6 Apr 1984	
59/117210	7 Jun 1984	
59/117211	7 Jun 1984	

(51) INT CL[4]
G02C 7/06

(52) Domestic classification
G2J S6AX S6D1

(56) Documents cited
GB A 2090426
GB A 2058391
GB A 2019030
GB 1484382
GB 1403675
GB 1295504
EP A2 0039497

(58) Field of search
G2J

(71) Applicant
Kabushiki Kaisha Suwa Seikosha (Japan),
4–1 2-chome Nishishinjuku, Shinjuku-ku, Tokyo, Japan

(72) Inventors
Toshihide Shinohara
Sakiho Okazaki

(74) Agent and/or Address for Service
J Miller & Co,
Lincoln House, 296–302 High Holborn, London WC1V 7JH

(54) **Progressive multifocal ophthalmic lens**

(57) A progressive mutlifocal ophthalmic lens comprises far (1) and near (3) viewing zones and an intermediate vision viewing zone (2) a principal meridian curve (M) the surface power along which in said zone (2) progressively increases from a far zone reference focal power (DI diopters) to a near zone reference focal power (D2 diopters); the additional power Ad (Ad = D2 – D1) being 1.5 diopters or more, given that the principal curvatures at each arbitrary point on the refractive surface are C1 and C2, each point on said refractive surface in said zone (2) central portion satisfying the condition;

$$|C1 - C2| \leqq 1/(N-1)\ (m^{-1}),$$

and each point on said refractive surface in said zone (1) central portion satisfying the conditions;

Continued overleaf . . .

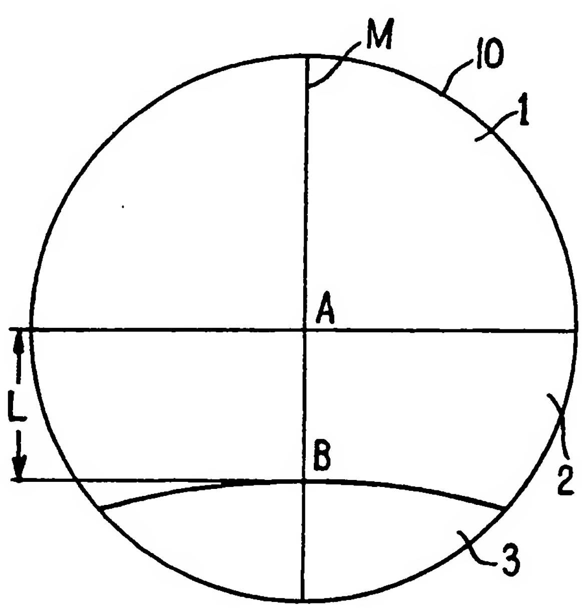

FIG.6

GB 2 146 791 A

$$|C1 - C2| \leqq 1/(N-1)\ (m^{-1}),$$

$$\frac{D_2 - 0.5}{N-1} \leqq \frac{C1 + C2}{2} \leqq \frac{D_2 + 0.5}{N-1} (m^{-1})$$

where N is the refractive index of the lens material; given that the minimum width of said zone (2) central portion and the maximum width of said near zone (1) central portion are S(mm) and W(mm), respectively, said minimum width S and said maximum width W satisfy the conditions:

$W \leqq 30/A$ (mm)
$W \leqq 1.5 \times S$ (mm)

where A is the value of the additional power Ad expressed in units of diopters; and given that the gradient of the variation of the surface power at each arbitrary point along said curve (m) is G(diopter/mm), every point along said curve (m) in said zone (2) satisfies the condition;

$G \leqq Ad/18$ (diopter/mm),

where Ad is the additional power in units of diopters.

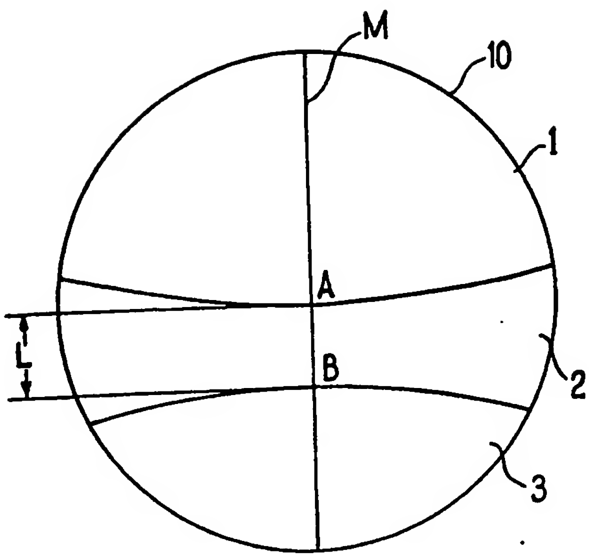

FIG.1

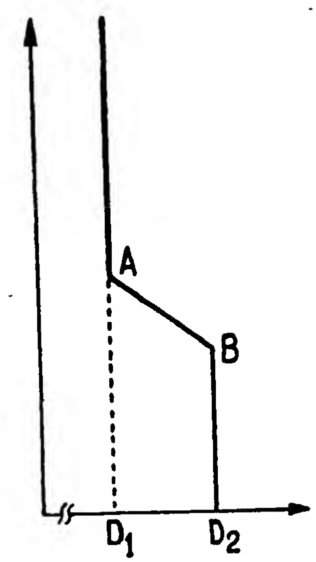

FIG.2

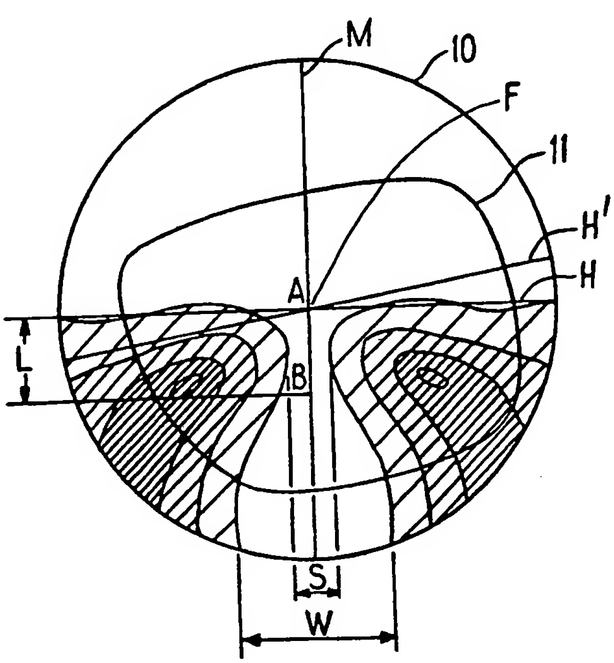

FIG.3

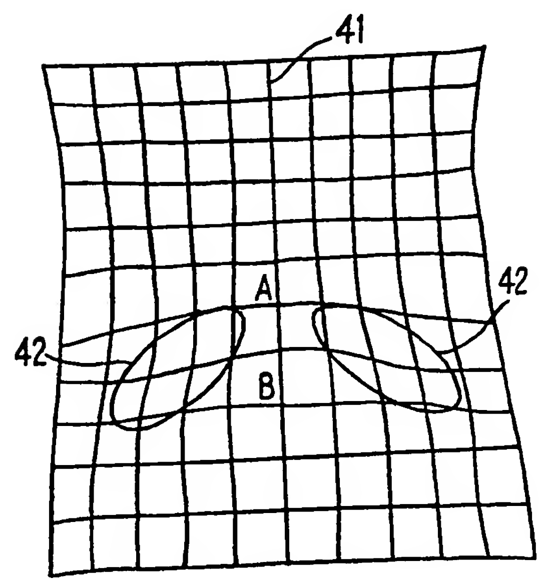

FIG.4

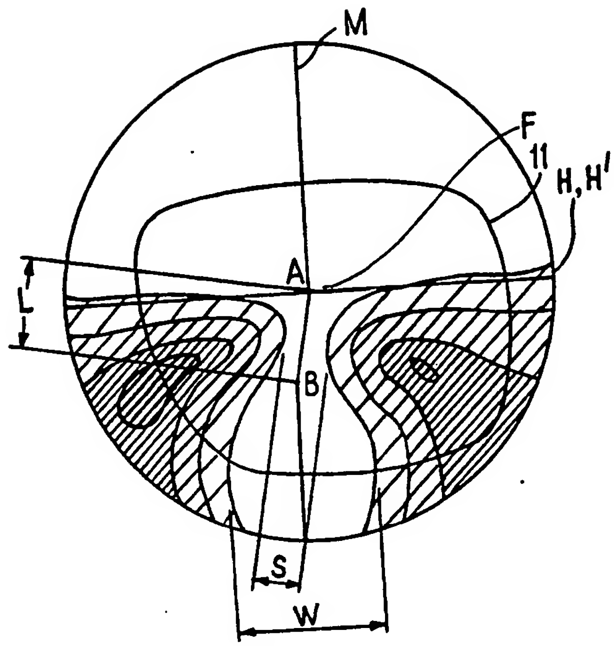

FIG.5

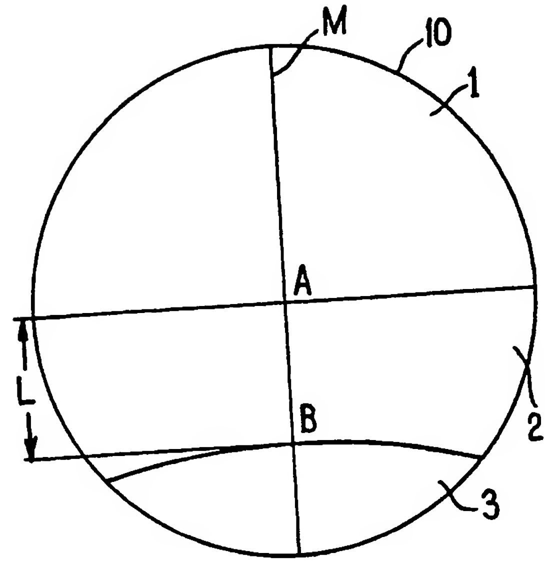

FIG.6

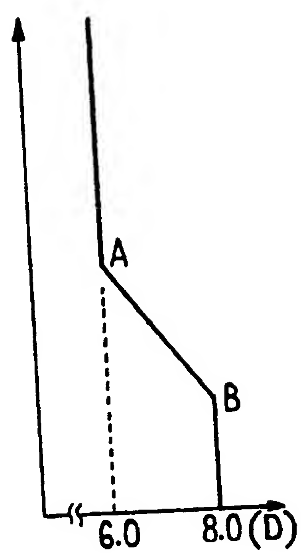

FIG.7

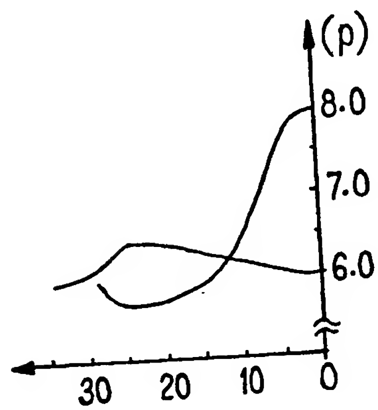

FIG.8

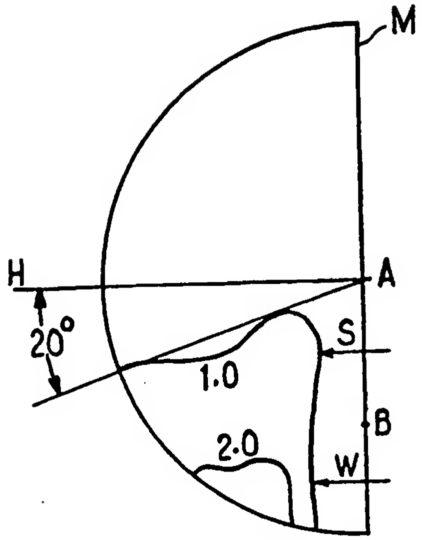

FIG.9

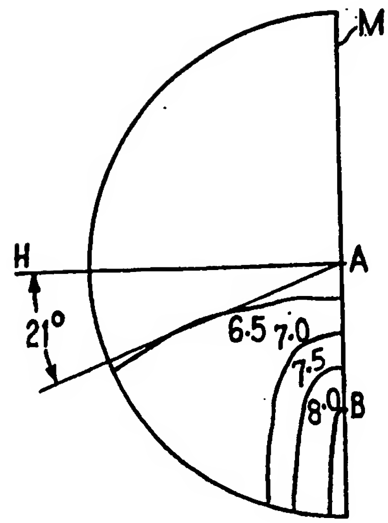

FIG.10

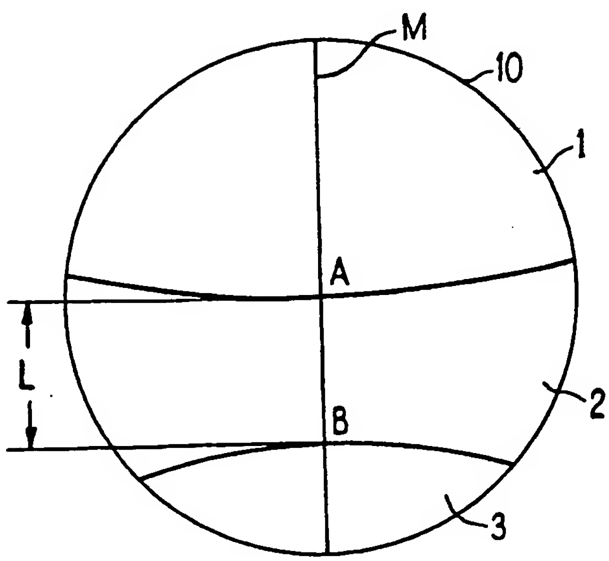

FIG.11

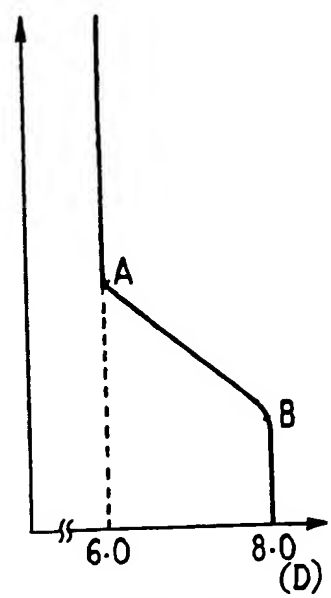

FIG.12

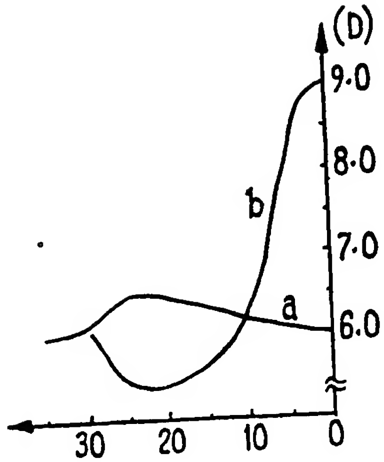

FIG.13

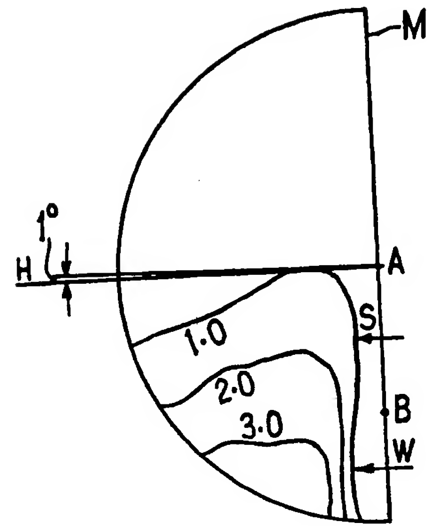

FIG.14

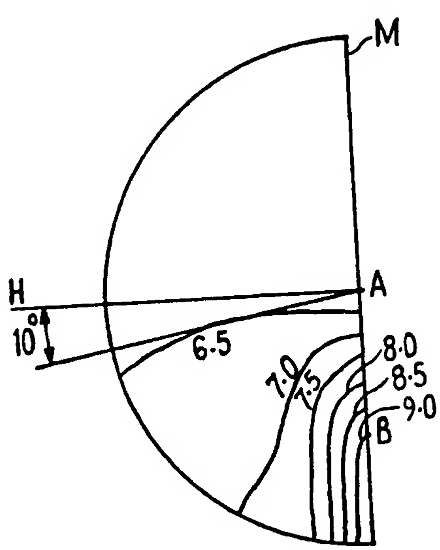

FIG.15

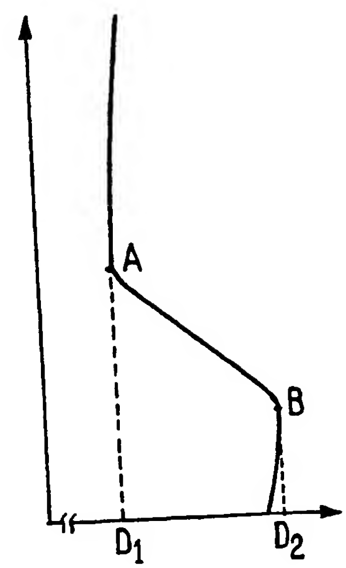

FIG.16

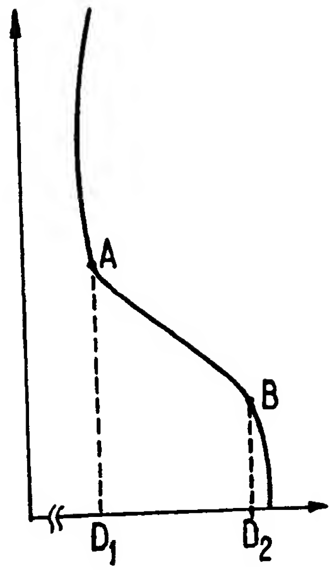

FIG.17

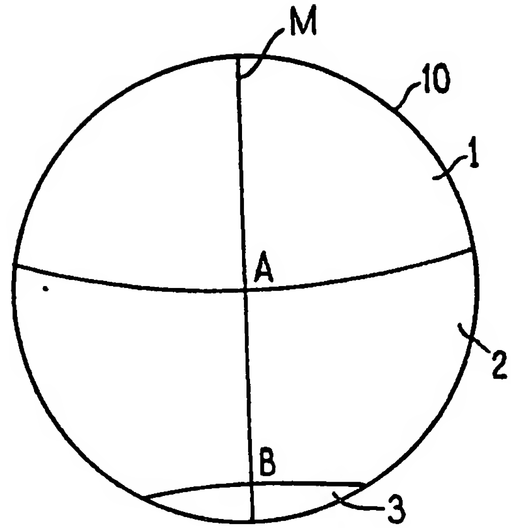

FIG.18

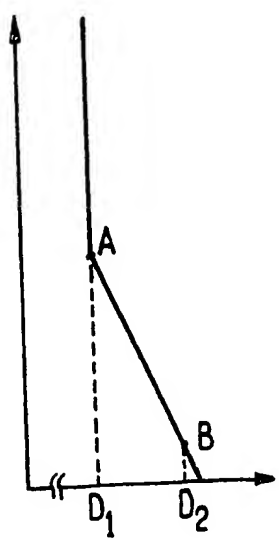

FIG.19

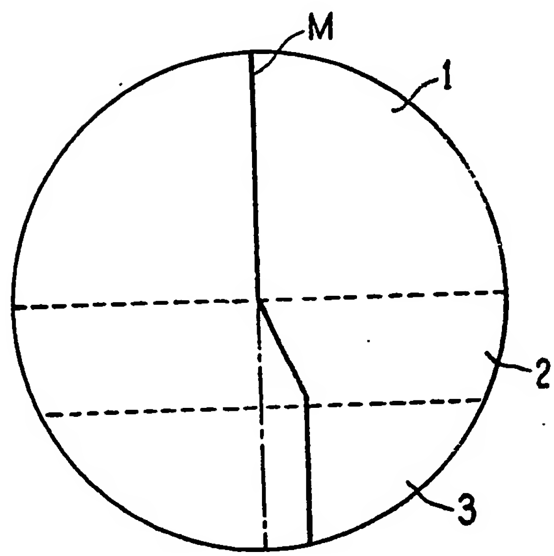

FIG.20

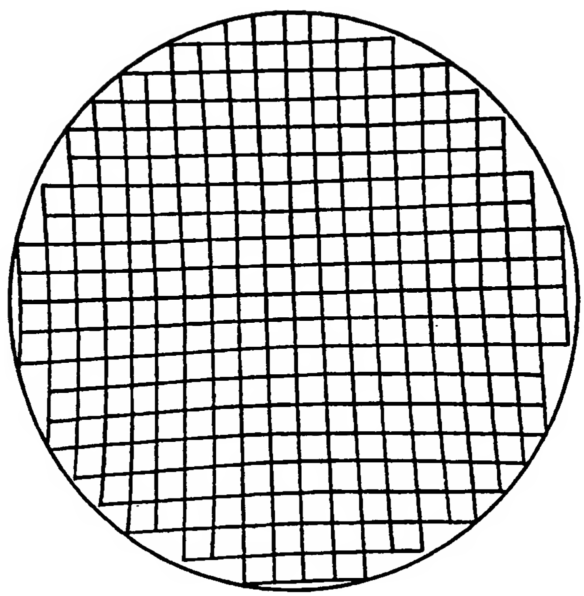

FIG. 21

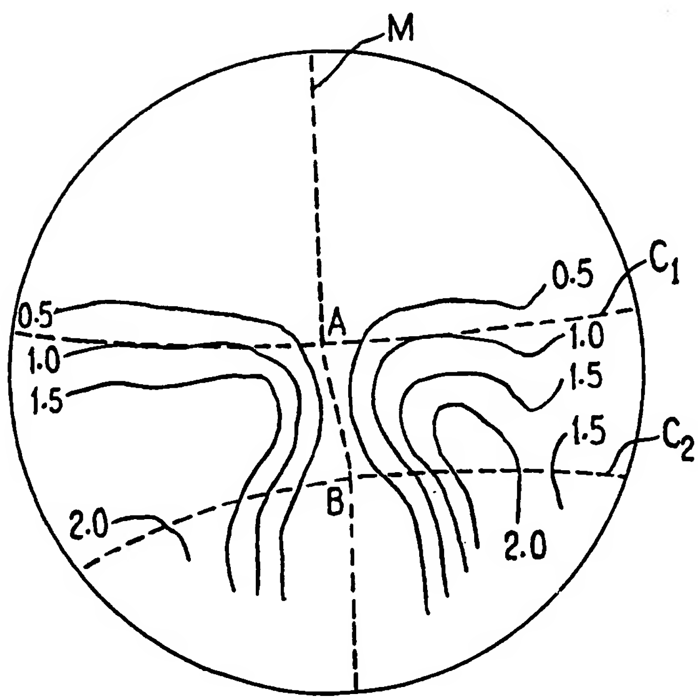

FIG.22

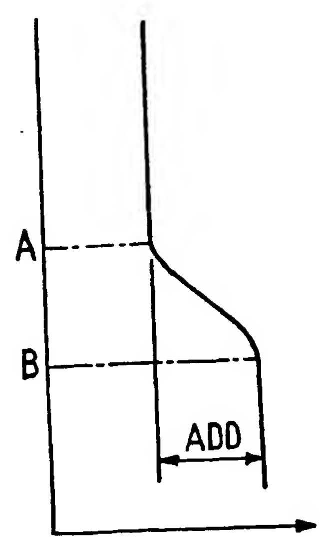

FIG.23

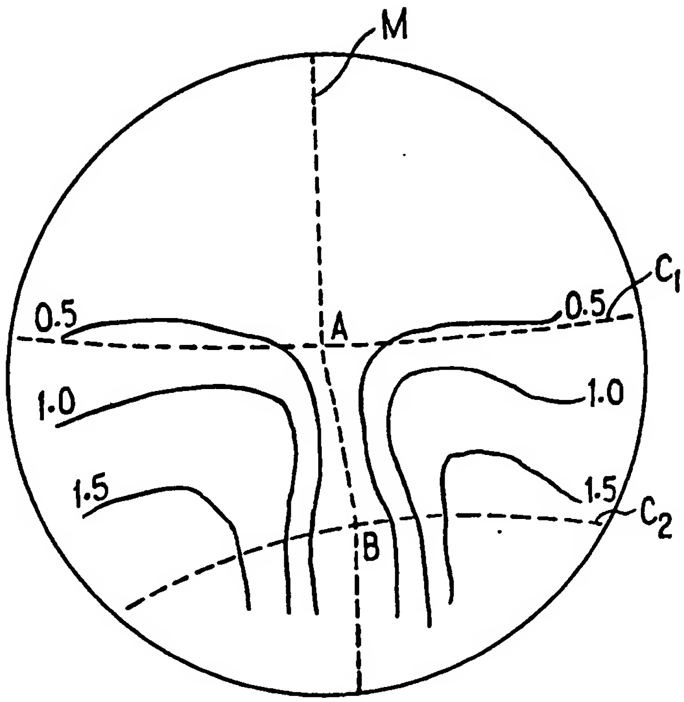

FIG. 24

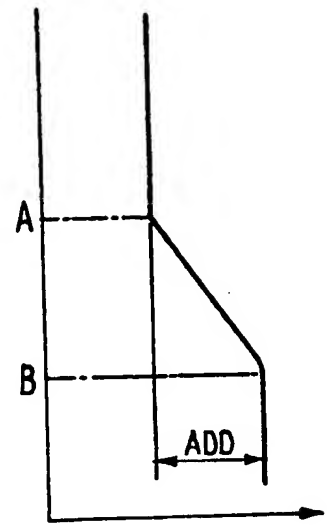

FIG. 25

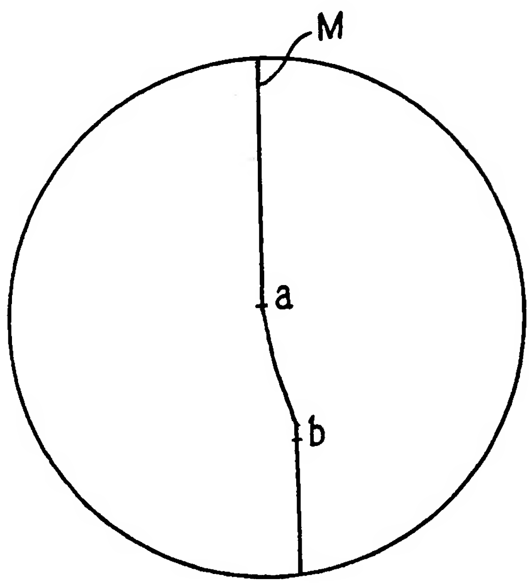

FIG. 26

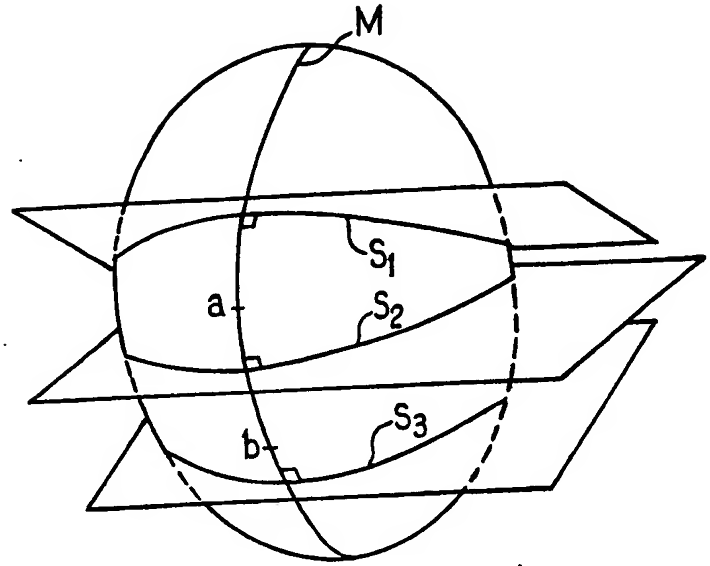

FIG. 27

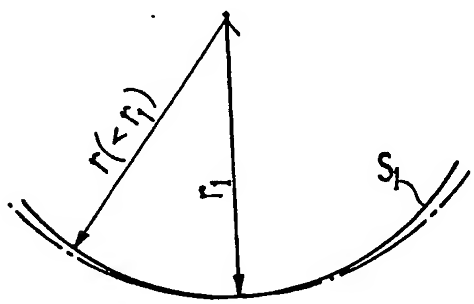

FIG. 28 (a)

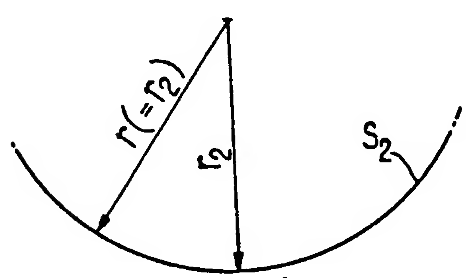

FIG. 28 (b)

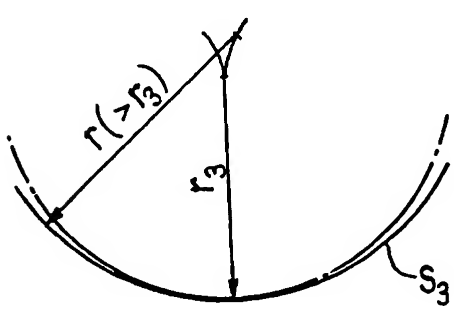

FIG. 28 (c)

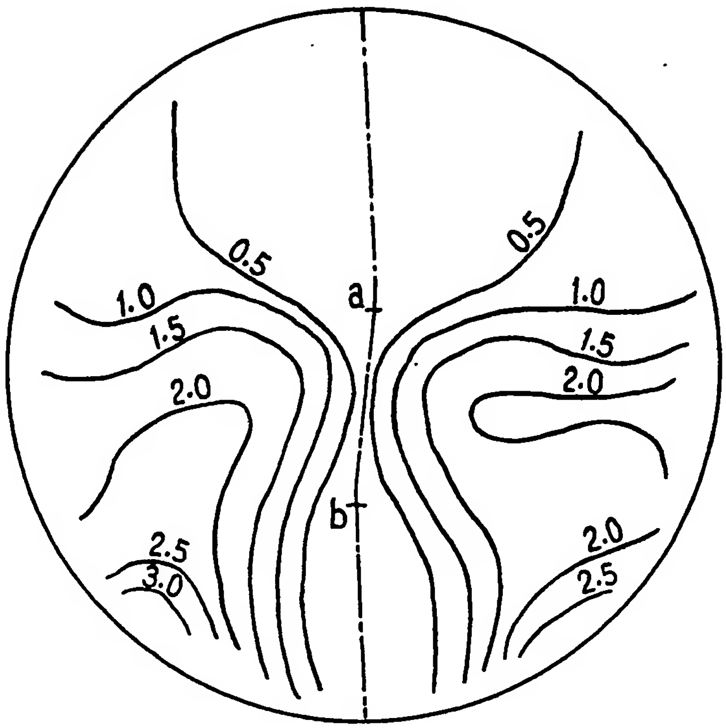

FIG.29

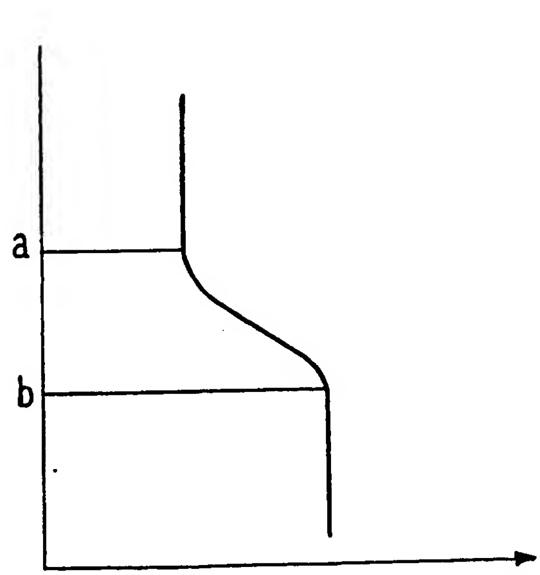

FIG.30

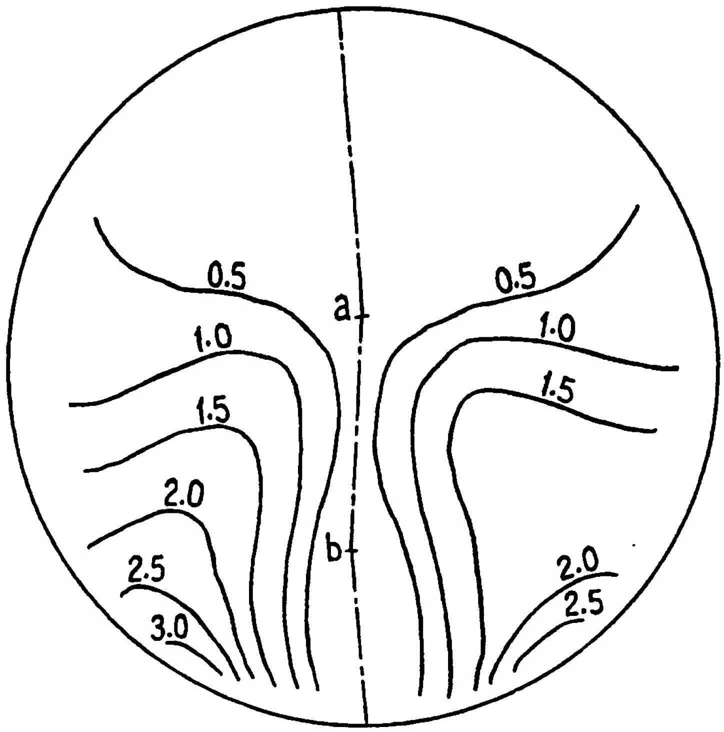

FIG. 31

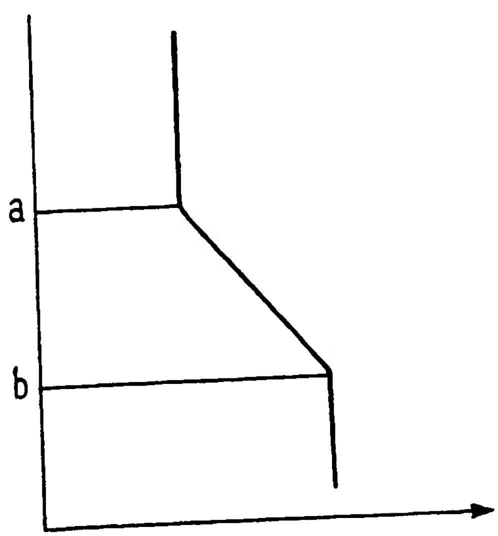

FIG. 32

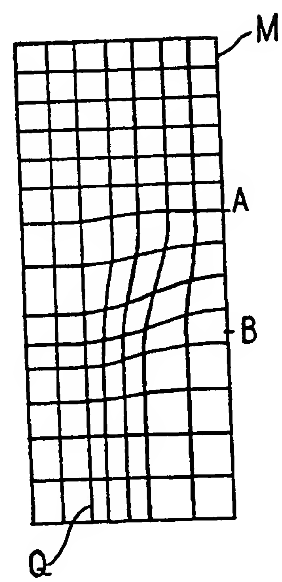

FIG.33

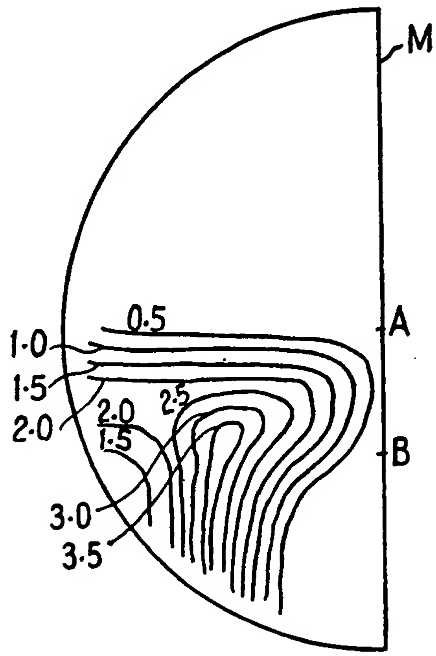

FIG.34

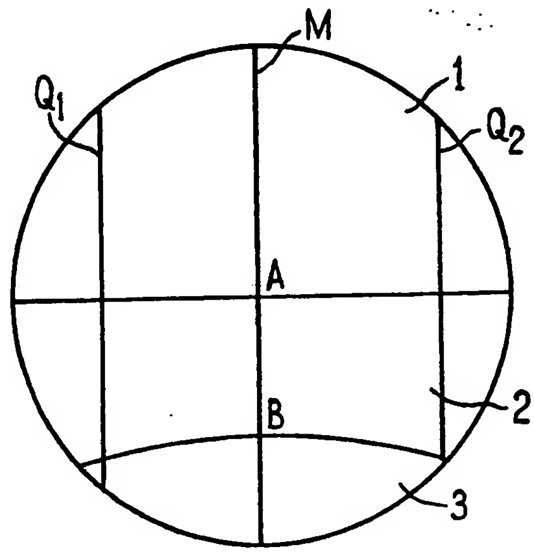

FIG.35

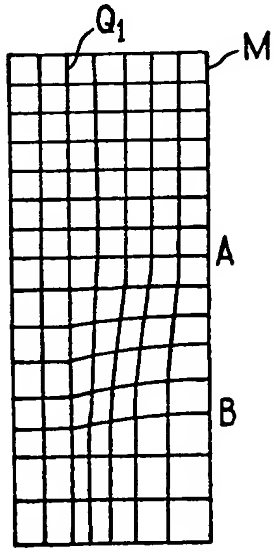

FIG.36

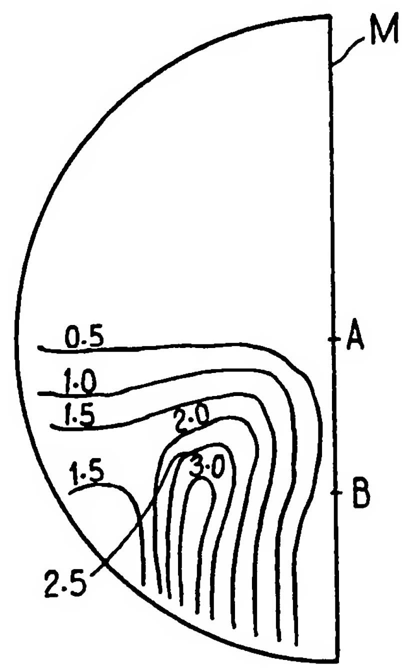

FIG.37

SPECIFICATION

Progressive multifocal ophthalmic lens

This invention generally relates to a progressive multifocal ophthalmic lens, and more particularly, to the configuration of the refractive surface of a progressive multifocal ophthalmic lens.

Progressive multifocal ophthalmic lenses have been developed to compensate for the decreased ability of the eye to control the crystalline lens in an aged person. A number of types of these progressive multifocal ophthalmic lenses have been introduced including those shown in U.S. Patent No. 3,687,528 and its British counterpart 1,295,504; U.S. 3,910,691 (corresponding to G.B. 1,403,675); U.S. 4,506,311 (corresponding to G.B. 1,484,382); E.P. Publication No. 39,497; U.S. 4,240,719 (corresponding to G.B. 1,580,484); U.S. 4,315,673 (corresponding to GB 2,019,030); U.S. 4,253,747 (corresponding to G.B. 2,020,847); GB 2,092,772A, U.S. Patent Application No. 180,765 (corresponding to GB 2,058,391) and U.S. Patent Application No. 327,288 (corresponding to G.B. 2,090,426), the last two of which are by the inventors of the present invention.

The basic construction of the progressive multifocal ophthalmic lenses disclosed in the above patents or patent applications is summarized below.

A progressive multifocal ophthalmic lens generally contains a segment for viewing distant objects and a segment for viewing nearby objects at the upper and the lower portions of the lens, respectively and a third segment for viewing intermediate objects between the above two segments. These three segments are called "the far vision viewing zone" (hereinafter referred to as "the far zone"), "the near vision viewing zone" (hereinafter referred to as "the near zone") and "the intermediate vision viewing zone" (hereinafter referred to as "the intermediate zone"), respectively, and these zones are divided into left and right parts by the principal meridian curve which extends vertically. In at least the intermediate zone, the surface power varies progressively. The demarcations of these segments are made to be smooth so that the demarcations are not perceived by the wearer of the lens. These three segments are usually provided on the convex surface of the two refractive convex and concave surfaces constituting the lens. The other surface of the lens is then provided with a spherical or toric surface designed specifically to correct the long-sightedness, the short-sightedness, the astigmatism and so on of the wearer.

Although the present invention is primarily directed to any novel integer or step, or combination of integers or steps, as herein described and/or as shown in the accompanying drawings, nevertheless, according to one particular aspect of the present invention, to which, however, the invention is in no way restricted, there is provided a progressive multifocal ophthalmic lens comprising two refractive surfaces facing each other;

at least one of said two refractive surfaces further comprising a far vision viewing zone for viewing mainly distant objects and a near vision viewing zone for viewing mainly nearby objects at the top and the bottom of said one refractive surface, respectively, and an intermediate vision viewing zone for viewing mainly intermediate objects between said two zones;

said intermediate vision viewing zone having an intermediate vision viewing zone central portion and said near vision viewing zone having a near vision viewing zone central portion;

at least one of said two refractive surfaces having a principal meridian curve extending vertically in the general centre of said far, intermediate and near vision viewing zones;

the surface power along said principal meridian curve in said intermediate vision viewing zone progressively increasing from a far vision viewing zone reference focal power (Dl diopters) to a near vision viewing zone reference focal power (D2 diopters);

the additional power Ad [Ad = D2–D1] of said at least one of said two refractive surface being 1.5 diopters or more,

said intermediate vision viewing zone central portion and said near vision viewing zone central portion extending on left and right sides of said principal meridian curve;

given that the principal curvatures at each arbitrary point on said refractive surface are C1 and C2, each point on said refractive surface in said intermediate vision viewing zone central portion satisfying the condition;

$$[C1 - C2] \leqq 1/(N-1)\ (m^{-1}).$$

and each point on said refractive surface in said near vision viewing zone central portion satisfying the conditions;

$$[C1 - C2] \leqq 1/(N-1)\ (m^{-1})$$

$$\frac{D_2 - 0.5}{N - 1} \leqq \frac{C1 + C2}{2} \leqq \frac{D_2 + 0.5}{N - 1} (m^{-1})$$

where N is the refractive index of the lens material;

given that the minimunm width of said intermediate vision viewing zone central portion and the maximum width of said near vision viewing zone central portion are S(mm) and W(mm), respectively,

said minimum width S and said maximum width W satisfy the conditions;

$W \leqq 30/A$ (mm)

$W \leqq 1.5 \times S$ (mm)

where A is the value of the additional power Ad expressed in units of diopters.

and given that the gradient of the variation of the surface power at each arbitrary point along said principal meridian curve is G (diopter/mm),

every point along said principal meridian curve in said intermediate vision viewing zone satisfies the condition;

$G \leqq Ad/18$ (diopter/mm),

where Ad is the additional power in units of diopters

In one embodiment the arrangement is such that each point on said refractive surface above a straight line starting at the fitting point and drawn on both sides downwardly by an angle of substantially K degrees from the horizontal line of said lens when said lens is glazed satisfies the conditions;

$[C1 - C2] \leqq 1/(N - 1)$ (m^{-1})

$$\frac{D_1 - 0.5}{N - 1} \leqq \frac{C1 + C2}{2} \leqq \frac{D_1 + 0.5}{N - 1} (m^{-1})$$

where K is calculated from the formula;

$K = 50 - A \times 20$,

in which A is the value of the additional power Ad expressed in units of diopters.

In this case, the surface power along said principal meridian curve may be constant in said far vision viewing zone and in said near vision viewing zone, respectively; and in said intermediate viewing zone, the angle formed by the normal line at each point along the intersection of a plane parallel with said principal meridian curve and said refractive surface and a plane containing said principal meridian curve changes in the same manner as the change of the surface power along said principal meridian curve in said intermediate vision viewing zone.

Moreover, it may be arranged that the surface power along the intersection of a plane orthogonal to said principal meridian curve on said refractive surface, in a direction away from said principal meridian curve, in said far vision viewing zone, is constant for a certain distance from said principal meridian curve, then progressively increases for the predetermined distance and then progressively decreases, and in said near vision viewing zone, is constant for a certain distance, then progressively decreases for the predetermined distance, and then progressively increases.

In another embodiment, said refractive surface is divided into a nose-side segment and a temple-side segment by a principal gazing line extending from the far vision viewing zone to the near vision viewing zone, and

in said intermediate vision viewing zone and said near vision viewing zone, the horizontal and the vertical differences in the distortion between said nose-side segment and said temple-side segment are less than the tolerance in humans.

In yet another embodiment, said refractive surface includes an umbilical curve extending vertically in the general centre of said refractive surface, and said refractive surface further comprises a section of said refractive surface taken along a plane orthogonal to said umbilical curve somewhere between the optical centres of the far vision viewing zone and the near vision viewing zone,

said section being of substantially circular shape with a radius of curvature having a value equal to that of the radius of curvature of said umbilical curve at the point of intersection of said umbilical curve with said section of substantially circular shape, and dividing said refractive surface into an upper portion in which sections taken along a plane orthogonal to said umbilical curve has the value of the radius of curvature decreasing in a direction away from said umbilical curve, and a lower portion in which sections thereof have the value of the radius of curvature increasing in the direction away from said umbilical curve.

The arrangement may also be such that in a portion outside a point 20 to 25mm apart from said umbilical curve, the principal axes of the principal curvatures at each point on said refractive surface lie in the vertical direction and the horizontal direction.

The invention also comprises spectacles provided with progressive multifocal ophthalmic lenses as set forth above.

The invention is illustrated, merely by way of example, in the accompanying drawings, in which:—

Figures 1 to 4 respectively illustrate the structure of the convex refractive surface of a known progressive multifocal opthalmic lens, the focal power variation along the principal meridian curve thereof, and the distribution of the astigmatism of and the distortion of the images of the square grids when viewed through such a lens,

Figure 5 illustrates the distribution of the astigmatism of another known progressive multifocal ophthalmic lens,

Figures 6 to 10 respectively illustrate the structure of the convex refractive surface of a first embodiment of a progressive multifocal ophthalmic lens according to the present invention, the focal power variation along the principal meridian curve thereof, the variation of the focal power on the intersection of the refractive surface and the plane orthogonal to the principal meridian curve in the far vision viewing zone and the near vision viewing zone thereof, and the distribution of the mean focal power thereof,

Figures 11 to 15 illustrate the structure of the convex refractive surface of a second embodiment of a progressive multifocal ophthalmic lens according to the present invention, the focal power variation along the principal meridian curve thereof, the variation of the focal power on the intersection of the refractive surface and the plan orthogonal to the principal meridian curve in the far vision viewing zone and the near vision viewing zone thereof, and the distribution of the astigmatism of and the distribution of the mean focal power thereof,

Figures 16 and 17 illustrate other examples of the focal power variation along the principal meridian curve,

Figures 18 and 19 illustrate further examples of the focal power variation along the principal meridian curve.

Figure 20 is a plan view of the refractive surface of the progressive multifocal lens disclosed in European Patent Publication No. 39,497,

Figure 21 illustrates the distortion of the images of the square grids when viewed through the lens of Fig. 20 for the purpose of explaining the difference between the distortions of the images perceived by both eyes,

Figures 22 and 23 respectively illustrate the distribution of the astigmatism and the focal power variation along the principal gazing line of the lens of Fig. 20,

Figures 24 and 25 respectively illustrate the distribution of the astigmatism and the focal power variation along the principal gazing line of a third embodiment of the present invention,

Figure 26 is a plan view of the refractive surface of the progressive multifocal ophthalmic lens disclosed in U.S. Patents No. 3,687,528 and 3,910,601,

Figures 27 and 28(a) to 28(c) are provided for explaining the configuration of the section of the refractive surface of the lens of Fig. 26 taken along a plane orthogonal to the umbilical curve wherein

S1, S2, S3 is the section of the refractive surface at each point,

R1, R2, R3 is the radius of curvature at the intersection of each section and the umbilical curve, and

R is the radius of curvature of the section at the point apart from the umbilical curve and indicates the difference in the size from R1, R2, R3, respectively,

Figures 29 and 30 respectively illustrate the distribution of the astigmatism and the focal power variation along the umbilical curve of the progressive multifocal ophthalmic lens of Fig. 26,

Figures 31 and 32 respectively illustrate the distribution of the astigmatism and the focal power variation along the umbilical curve of a fourth embodiment of the present invention,

Figures 33 and 34 respectively illustrate the distortion of the images of the square grids when viewed through the progressive multifocal ophthalmic lens disclosed in the U.S. Patent No. 4,056,311 and the distribution of the astigmatism of the same lens,

Figure 35 is a plan view of the refractive surface of the progressive multifocal ophthalmic lens of a fifth embodiment of the present invention, and

Figures 36 and 37 respectively illustrate the distortion of the images of the square grids when viewed through the progressive multifocal opthalmic lens of Fig. 35 and the distribution of the astigmatism of the same lens.

The basic construction of a previously suggested multifocal ophthalmic lens is described in more detail with reference to Figs. 1 to 4 of the drawings.

Fig. 1 is a plan view of the refractive surface of a lens body 10 of a progressive multifocal lens, showing the arrangement of different segments thereof. In Fig. 1, 1, 2 and 3 are the far zone, the intermediate zone and the near zone, respectively and M is the principal meridian curve.

Fig. 2 illustrates the variation of the surface power along the principal meridian curve M. The surface power is expressed by:

$$\text{surface powr} = C \times (N - 1)$$

where C is the curvature in units of metres, N is the refractive index of the lens material, and the surface power is in units of diopter (hereinafter referred to as D).

As shown in Figs. 1 and 2, the surface power along the principal meridian curve above the point A, that is in the far zone, is D1, and that below the point B, that is in the near zone, is D2. Between the points A and B, the surface power progressively increases from D1 to D2. The difference between D1 and D2 (D2 − D1) is referred to as the additional power, which additional power is usually between 0.5 and 3.5D. In Fig. 2, the surface powers in the far zone and in the near zone respectively, are constant as an example. However, as will be described later, there is another example in which the surface power in at least one of the far and the near zones progressively varies. In such a case, D1 and D2 are not defined and consequently, the additional power of the lens cannot be evauluated. Accordingly, in order to determine the additional power of a lens of this kind, a reference surface power is defined in each zone. Hereinafter D1 and D2 represents the far zone reference power and the near zone reference focal power, respectively.

In Fig. 1, the length L between the points A and B is referred to as the length of the intermediate zone or the length of the progressive portion.

As mentioned above, in the progressive multifocal ophthalmic lens, since a plurality of separate segments of different focal powers are combined into one smooth curved surface, at least the intermediate zone is inevitably aspherical. As a result, astigmatism appears in the peripheral portions of the lens. In addition, since the magnifications of images seen through the various portions of the refractive surface are different, the images are distorted. These defects are illustrated by Figs. 3 and 4.

Fig. 3 is a contour of the astigmatism for explaining the distribution of the astigmatism of the lens of Fig. 1. In this case, the astigmatism is obtained by converting the difference in the principal curvatures of the refractive surface into the differences in the surface power. That is, since the refractive surface of the progressive multifocal ophthalmic lens is aspherical, the curvature at a certain point (or a minute plane) is different depending upon the direction. The maximum and the minimum of the curvatures in the various directions at a certain point are called the principal curvatures. Given that the principal curvatures expressed in units of m^{-1} are C1, C2, the astigmatism is obtained by the formula:

$$\text{astigmatism} = |C1 - C2| \times (N - 1)$$

and the units are D. The astigmatism is perceived by the wearer of the lens as the blurring of the images, and astigmatism exceeding 0.5D usually causes the wearer to feel nausuea.

In Fig. 3, the more dense the shading, the larger is the astigmatism and consequently the more severe is the blurring of the images.

The principal meridian curve usually forms an umbilical curve. The umbilical curve is a series of points where the principal curvatures are equal, that is, it is a minute spherical surface along which the astigmatism is essentially O. Even if the principal meridian curve does not form an umbilical curve, the astigmatism along the principal meridian curve is made to be the smallest.

Fig. 4 illustrates distortion of the images of the square grid when viewed through the progressive multifocal ophthalmic lens of Fig. 1. The difference in the magnification in each portion of the refractive surface causes the distortion of the images of the square grid. As shown in Fig. 4, the vertical lines laterally expand in the downward direction with respect to the centre line 41 which corresponds to the principal meridian curve of the lens, and the horizontal lines are downwardly skewed in the peripheral portions. Such skew distortion of the images is not only perceived as a distortion of the vision by the wearer, but also cause the images to appear to shake when the objects being viewed move relatively with respect to the line of vision of the wearer, such as when the wearer follows an object with his eyes or watches something while turning his head. As a result, the wearer may feel nausea.

In using such progressive multifocal lenses in spectacles, the lens body 10 is cut to the internal eye shape. In the cutting process, it is required to define the fitting point and the insetting of lenses to adapt for convergence.

The fitting point is the position on the refractive surface of the lens through which the line of vision of the wearer passes when he looks at the far distance in the natural position, and is sometimes called "the eye point". Generally, the fitting point is defined on the principal meridian curve between the point A and a point 2mm to 3mm above A. In Fig. 3, the fitting point F is coincident with the point A.

Convergence means that the line of vision moves more inside when looking at nearby objects than when looking at distant objects. Accordingly, when making spectacles, the lenses are required to be arranged so that the distance between the points B of both lenses is shorter than the distance between the points A of both lenses. In other words, the lenses are inset. In general, the lens as shown in Fig. 3, which is designed so that the left and the right halves are symmetrical with respect to the principal meridian curve M, is used for spectacles by rotating the lens through an angle of about 10°. For example, assuming that the lens of Fig. 3 is viewed from the side of the convex surface of the lens, the lens is used as the spectacle lens for the left eye on the basis that the horizontal line H (the line orthogonal to the principal meridian curve M) is rotated by about 10° to the line H' (hereinafter referred to as the horizontal line H' when glazed). Accordingly, the configuration of the lens for spectacles after the cutting process is shown by the curve 11. In Fig. 3 only the configuration of the lens for the left eye is shown but not for the right eye. When preparing the spectacle lens for the right eye, the horizontal line H is rotated in the direction opposite to that in which the horizontal line H' for the left eye, when glazed, is rotated.

Another type of progressive multifocal ophthalmic lens is shown in Fig. 5, in which the left and the right halves of the refractive surface thereof are asymmetric. In the case of Fig. 5, the principal meridian curve M is inclined in the middle portion of the lens and the horizontal line H of the lens need not be rotated for use in spectacles. The lens of Fig. 5 is designed for the left eye and the curve 11 shows the configuration of the lens after the cutting process. In designing this type of ophthalmic lens for the right eye, the principal meridian curve M between the points A and B is inclined in the opposite direction to the direction shown in Fig. 5.

The above-mentioned progressive multifocal ophthalmic lenses are only examples of known lenses and there are many other lenses having the same basic construction and still giving the wearer different wearing sensations. The fact that there are so many kinds of progressive multifocal ophthalmic lenses demonstrates that the ideal design for a progressive multifocal ophthalmic lens is difficult to realize. In other words, in designing a progressive multifocal ophthalmic lens, there is a significant problem in that if one characteristic is improved, another characteristic is affected.

Among many characteristics of progressive multifocal ophthalmic lens affecting each other, those which restrict the design of lenses most considerably are the so-called "dynamic vision" and "static vision".

"Dynamic vision" is the vision in the case where the object moves relative to the line of vision, such as occurs when gazing at a moving object or when watching something while turning one's head. "Static vision" is the vision in the case where the line of vision and the object are both almost still. Considering the designing of a progressive multifocal ophthalmic lens, the dynamic vision is affected mainly by the distortion of the images so that the smaller is the distortion of the images, the better is the dynamic vision. On the other hand, the static vision is affected mainly by astigmatism, and the smaller is the astigmatism of the total refractive surface of the lens or the larger is the area of the region having the small astigmatism (for example, a region having an astigmatism of no more than 0.5D), the better is the static vision.

If the region having the smaller astigmatism is designed to be larger in order to obtain good static vision, the magnification changes abruptly around the region, that is, in the lateral portions of the lens and thus the distortion of the images becomes severe, so that the dynamic vision deteriorates. On the contrary, if the dynamic vision is improved, the area of the region with the small astigmatism in the far and the near zones is reduced and the static vision is affected.

Accordingly, the balance of the dynamic vision and the static vision is considered to be one of the most important factors in designing a progressive multifocal ophthalmic lens. If can be said that the difference between the various designs of progressive multifocal ophthalmic lens is ultimately the difference in the degree of giving priority to either dynamic or static vision. In some lenses, as a result of concentrating on the improvement of the static vision rather than on that of the dynamic vision, the refractive surface in the far zone as a whole is made to be spherical and a large spherical part is also provided in the centre of the near zone. In this case, while the static vision is improved, the distortion of the images is very severe in the lateral portions of the intermediate and the near zones, and the dynamic vision is impaired. In another

lens, as a result of concentrating on the improvement of the dynamic vision rather than on that of the static vision, the far and the near zones are both provided with aspherical surfaces in order to reduce the distortion of the images as a whole. Accordingly, the region with the small astigmatism becomes narrow, and the static vsion is affected.

In spite of differences in the priority given to the dynamic vision and the static vision as mentioned above, the designers of known progressive multifocal ophthalmic lenses have had one common basic conception. That is, they have attempted to design a progressive multifocal lens which may be used for a number of different purposes. In general, a progressive multifocal ophthalmic lens has been designed for the presbyopic and while the priorities of the far, the intermediate and the near zones are almost equal, the area of the near zone tends to be larger than that of the other zones.

In the case of certain specific uses, however, the known multi-purpose progressive multifocal lens is not necessarily most suitable and it is often very inconvenient. For example, such a lens is not especially suitable when engaging in sports (such as golf), shopping, driving a car and the like. The requirements in designing a progressive multifocal ophthalmic lens for use in such conditions as above may not be fully met by the known multi-purpose progressive multifocal lens. Some of the lenses with small additional power (0.5 to 1.25D) do have appropriate characteristics (because if the additional power is small, astigmatism can be essentially reduced). However, despite the fact that moderate or large additional powers are required in progressive multifocal ophthalmic lenses, known lenses with such large additional powers are not suitable for use in the above circumstances.

In order to obtain an optimal progressive multifocal lens for use in sports, shopping or driving a car, it is necessary to avoid the conventional concentration on either the dynamic vision or the static vision. Instead, the qualities of both the dynamic vision and the static vision are kept equally high in the far and in the intermediate zones at a slight expense of the quality of both the dynamic vision and the static visions in the near zone. The requirements for the three zones of the progressive multifocal lens to be designed in accordance with the above conceptions are explained below.

The requirement for the far zone is that even when the wearer watches an object on one side of him without moving his head, there is no blurring, distortion and shaking of the image. It is also preferable if such blurring, distortion and shaking of the image is not perceived when the wearer watches an object lying in a region to one side of him and a little below the horizontal line. (This region can be regarded as a part of the intermediate zone, through the requirement for that portion is the same). For example, when driving away in golf, it is essential that the far vision should be wide and that any shaking of the image should be small. When driving a car, the larger the far vision and the smaller the blurring and distortion of the latter, the better. In this case, since the peripheral portion of the lens is not used frequently and is out of line of sight, the blurring and distortion of the images which are seen when looking through the peripheral portions of the lens can be accepted to a certain degree.

In the intermediate zone, it is required that the width of the region through which the image is viewed without blurring is large and the distortion and the shaking of the images are small in the lateral portions thereof. The intermediate zone especially plays an important role when one considers the nature of the grass on the putting green in golfing, the display of the mileage on a car, the price and the like on the label of the goods in show-windows in shopping, and so on.

With respect to the near zone, the width of the region where the blurring of the images is not produced should be at the minimum acceptable value. Of course, the larger the width of this region, the better. However, such a region in the near zone is reduced in order to improve the characteristics of the far and the intermediate zones. In engaging in golf, driving a car, shopping and so on, the near zone of a progressive multifocal lens is not very significant and it is rare that the near zone is used for a long time. In playing golf, for example, the characteristics of the near zone are fully acceptable provided the wearer can keep the score.

As mentioned before, the above requirements for the various zones are not met in any of the known progressive multifocal ophthalmic lenses. The characteristics of the actual progressive multifocal opthalmic lens are described below. The characteristics of lenses of this kind vary with the additional power. The following description is of a lens with the additional power of 2.0D. Also, the values of the astigmatism, the focal power and so on in the description are based on the results of experiments using a lensmeter with an opening having a diameter of 5mm.

First, the characteristic of the far zone is evaluated along the contour of astigmatism of 1.0D. Herein, the region with the atigmatism of up to 1.0D is considered to be the region through which the blurring or distortion of the images is not perceived very much. Generally, the upper limit of such a region as above is 0.5D. However, an experiment which we have carried out has demonstrated that in a design in which the astigmatism varies progressively, the upper limit of the region where "the blurring or distortion of the images is not very much perceived" is preferably 1.0D rather than 0.5D, having regard to the actual feeling of the wearer as explained later. Accordingly, the evaluation of the characteristic here is with respect to a contour of

astigmatism of 1.0D.

In Figs. 3 and 5, the region without shading has astigmatism of not more than 1.0D. In the lens of Fig. 3, which is designed to be bilateral-symmetrical, the contour of 1.0D lies 0 to 10° upwardly of the horizontal line H. In preparing this lens for spectacles, the lens is rotated about 10° for insetting as mentioned before. Accordingly, after insetting, the contour of 1.0D in the portion of the lens at the side of the nose (i.e. the lefthand of the lens of Fig. 3) lies 10 to 20° upwardly of the horizontal line H' when glazed. In this portion, the wearer views an object disposed at one side through a region of large astigmatism and consequently the images are blurred. The lens of Fig. 5, which is designed to be asymmetrical, is not required to be rotated for insetting. So the contour of 1.0D lies 0 to 10° upwardly of the horizontal line H (H'). Thus the vision through the lens of Fig. 5 is slightly better than that of Fig. 3, though it is still far from satisfactory Besides, the lens of Fig. 5 has the defect that the astigmatism or the distortion and shaking of the images increases in the portion from the lower part of the far zone to the upper part of the intermediate zone at the side of the nose (the lefthand of Fig. 5). The above defect is also present in a lens of a type which is bilateral-symmetrical and in which the static vision is emphasized (for example, a lens in which the whole portion above the horizontal line H is provided with a spherical surface).

Secondly, the characteristic of the intermediate zone is evaluated in terms of the minimum width S of the region in which the astigmatism is not more than 1.0D. In a known progressive multifocal ophthalmic lens, the mimimum width S is 3 to 8mm and in most cases S is 5 to 6mm. In defining the optimal value of S, the case where the wearer views an object disposed at a distance equivalent to the length of the arm (e.g. when reading the mileage in driving a car) is considered by way of example. In such a case, it is desirable that a region as wide as 20 to 30cm can be clearly viewed at a distance of about 60cm. Converting this into the width S, the optimal value of S is defined as about 8 to 12 mm, and thus the width S of the known progressive multifocal lens is too small.

In the meanwhile, the characteristic of the intermediate zone is evaluated in terms of the length L of the progressive portion. In the known progressive multifocal ophthalmic lens, the length L of the progressive portion is 10 to 16mm and the maximum gradient of the variation of the focal power along the principal meridian curve is 0.20 to 0.13D/mm. In the known lenses, the length L of the progressive portion is relatively small for various reasons. Thus, if the length L is too large, the line of vision is required to be directed considerably downwardly when using the near zone, i.e. in near vision viewing, and consequently, near vision viewing becomes very troublesome. As mentioned before, in the known multi-purpose lenses in which an attempt is made to provide clear viewing from distant to close positions, the near vision viewing cannot be sacrificed. Consdering them only with respect to intermediate vision viewing, however, these known lenses are very inconvenient. In other words, when the length L of the progressive portion is small and the gradient of focal power variation is large, even if the line of vision moves only a little, the focal power along the path of the line of vision changes abruptly. Accordingly., when looking at an object at an intermediate position, the suitable portion of the lens (that is, the portion having the suitable focal power for looking at an object at a certain distance) must be sought each time according to the distance from the eye to the object. Moreover, such a suitable portion of the lens is narrow. Also, the short progressive portion and the large gradient of focal power variation cause increased astigmatism, distortion and the shaking of the images in the lateral portion of the intermediate zone and give an uncomfortable view for the wearer of the lens.

Next, the characteristic of the near zone is evaluated in terms of the maximum width W of the region where the astigmatism is not more than 1.0D. In the known progressive multifocal lens, the maximum width W is about 20mm and is rarely more than 30mm. If one considers that it is sufficient if one page of a book (about 15cm at the distance of about 30cm) or less can be clearly viewed when urging near vision viewing such as reading, the optimal value of W may be defined as 15mm or less. Thus, W of the known lenses is too large. This large W affects not only the lateral portions of the near zone but also the lateral portions of the intermediate zone so that the astigmatism and the distortion and the shaking of the images increase in these portions. Furthermore, if W is large, the contour of the astigmatism of 1.0D, as described before with respect to the characteristic of the far zone, is pushed upwardly, thus affecting the far zone.

Finally, the minimum width S of the region with an astigmatism of not more than 1.0D in the intermediate zone is related to the maximum width W thereof in the near zone. In the known progressive multifocal ophthalmic lens, the maximum width W is from 2 to 3 times to 7 to 8 times as large as the minimum width S. As shown in Fig. 4, such a large difference between W and S as described above causes a large distortion of the images in portions beside the point B identified by the reference numeral 42 and makes the wearer of the lens tend to feel nausea.

Accordingly, it is an object of this invention to eliminate the above described problems of the known progressive multifocal ophthalmic lenses and provide a progressive multifocal ophthalmic lens which is especially suitable for use in active circumstances such as sports, driving a car,

walking, or shopping, i.e. a progressive multifocal ophthalmic lens having an excellent view of the far vision and the intermediate vision with little shaking and blurring of the images.

The progressive multifocal ophthalmic lens in accordance with this invention includes a refractive surface containing the large regions suitable for far vision viewing and for intermediate vision viewing respectively, and also containing a region suitable for near vision viewing which is as large as or a little larger than the region in the intermediate zone, the focal power along the peripheral meridian curve varying progressively.

The structure of the refractive surface of the progressive multifocal lens in accordance with one embodiment of this invention and the ground of utilizing such a structure are described in detail.

In order to improve the intermediate vision viewing through the intermediate zone, the gradient of the focal power variation along the principal meridian curve is required to be made easy. If the gradient of focal power variation is small, when looking at an object at an arbitrary distance, the region of the lens suitable for viewing the object is expanded in the vertical direction and the region where the astigmatism in the central portion including the principal meridian curve is not more than 1.0D (hereinafter referred to as the intermediate zone central portion) is expanded in the lateral direction. Both above effects improve the intermediate vision viewing. Although generally the smaller the gradient of the focal power variation the better, we made some experiments to define the optimal upper limit of the gradient for excellent intermediate vision viewing at which the present invention aims, taking its influence on the far and the near zones into account. The experiments were based on the provision of progressive multifocal lenses having a different length L of the progressive portion in which the focal power along the principal meridian curve in the intermediate zone was made to be linear, and controlled studies were conducted on these sample lenses employing tests during wear and so on. These studies demonstrated that the length L of the progressive portion is preferably at least 18mm. For example, in the case where l is 18mm and the additional power is 2.0D, the minimum width S of the intermediate zone central portion is about 9mm which is enough as mentioned before and the distortion and the shaking of the images through the lateral portions is small. When L is 18mm and the additional power is more than 2.0D, the gradient of the focal power variation becomes large, the minimum width S is a little reduced and consequently the distortion and shaking of the images slightly increases, although the condition is still within the allowable range to achieve the object of the present invention.

The optimal conditions for the intermediate vision viewing may be summarized as follows:

1. The astigmatism should be not more than 1.0D.
2. The gradient of the focal power variation should be no more than (additional power /18) D/mm.

Additionally, as a result of the sequential studies on the near vision viewing by tests during wear and various optical calculations, the optimal conditions for the near vision viewing are;

3 The astigmatism should be not more than 1.0D.
4. The mean focal power should be within the near zone reference focal power D1 ± 0.5D.

Condition 3 is the same as condition 1 for the intermediate zone central portion. In order to realize a lens having a portion in which conditions 3 and 4 are met, each point on one of the refractive surfaces constituting the lens in the near zone should be designed to satisfy the following two conditions;

3′ $|C1 - C2| \leqq 1/(N-1)\ (m^{-1})$

4′

$$\frac{D_2 - 0.5}{N-1} \leqq \frac{C1 + C2}{2} \leqq \frac{D_2 + 0.5}{N-1} (m^{-1})$$

where C1 and C2 are the principal curvatures at each point on the refractive surface (units: m^{-1}) and N is the refractive index of the lens material. When the configuration of the refractive surface of the lens is to be described accurately, the expression as conditions 3′ and 4′ should be used. However, since conditions 3′ and 4′ perfectly correspond to conditions 3 and 4, respectively, in the following dexcription the expression of conditions 3 and 4 is used for simplicity. The region in which these conditions 3 and 4 are met is referred to as the near zone central portion.

An attempt is made to define the optimal width of the near zone central portion in relation to the width of the intermediate zone central portion. When one is giving priority to the improvement of the far and the intermediate vision viewing and to the reduction of the distortion and shaking of images, the maximum width W of the near zone central portion should be at the smallest limit of the allowable range. As mentioned before, the maximum width W can be 15 mm or less. However, considering the fact that as the additional power increases, the distortion

and shaking of the images also increase, we have come to the conclusion that the optimal maximum width W according to the additional power may be expressed as:

$W \leqq 30/A$ (mm),

where A is the value of the additional power Ad expressed in units of diopters.

Further, in order to reduce the distortion and shaking of the images through the lateral portions of the intermediate and the near zones, the maximum width W of the near zone central portion should be 1.5 or less times as large as the minimum width S of the intermediate zone central portions, that is,

$W \leqq 1.5 \times S$ (mm).

In theory, in order to reduce the distortion and shaking of the images, the relation $W = S$ is the most favourable. However, in view of the width required for the near vision viewing, the above condition is considered to be optimal.

Hereinbefore, the conditions for the intermediate and the near vision viewing have been explained. If a progressive multifocal ophthalmic lens is designed so that all the requirements mentioned before are sufficient, the intermediate vision viewing and the near vision viewing are of course improved and at the same time, the far vision viewing is improved since the astigmatism in the far zone becomes small and the blurring of the images of the objects lying at a lateral position is reduced. Thus, an object of this invention is fully achieved by designing the progressive multifocal ophthalmic lens according to the above conditions.

Furthermore, the inventors of the present invention have studied the configuration of the refractive surface of the lens in the far zone in order to improve far vision viewing.

In theory, a far zone provided with a spherical surface provides excellent far vision viewing. However, if the whole far zone is spherical, the distortion and the shaking of the images through the intermediate and the near zones increases and the characteristics of the intermediate vision viewing and the near vision viewing may be impaired. Accordingly, in most progressive multifocal ophthalmic lenses, the far zone is provided with an aspherical surface. The inventors of the present invention have assessed the allowable degree of asphericity of the far zone, that is, the degree of aberration from a spherical surface and have found that there are the following two conditions for achieving an excellent far vision viewing like for the near zone central portion;

5. The astigmatism should not be more than 1.0D
6. The mean focal power should be within the far zone reference focal power

$D1 \pm 0.5D$

These conditions 5 and 6 are expressed in the same way as the before-mentioned conditions 3′ and 4′ respectively only if in 4′, D_2 is replaced by D_1.

Then the said inventors examined the optimal expanse for an excellent far vision viewing. Ideally, the refractive surface where the above two requirements are met should extend to as low as possible with respect to the horizontal line H′ when glazed. However, too wide a far zone results in increased distortion and shaking of the images through the intermediate zone. Moreover, as is well known, the larger is the additional power, the more is the distortion and shaking of the images. Consequently, considering the association with the additional power, the optimal expanse of the region of the refractive surface satisfying the above conditions 5, 6 has found to be the portion above the line drawn downwardly from the horizontal line when glazed by an angle of $[50 - (A \times 20)]$ degrees, in which A is the value of the additional power Ad expressed in units of diopters. If the sign of the result of the above subtraction is minus, the line inclines upwardly. For example, when the additional power is 2.0D, the region lies above the line drawn downwardly from the horizontal line when glazed by 10°, and when the additional power is 3.0D, the region lies above the line upwardly from the horizontal line when glazed by 10°. By locating the region satisfying the before-mentioned two conditions 5, 6 as above, a highly desirable progressive multifocal ophthalmic lens is obtained. However, it is not necessarily required that the total surface above the line satisfies the conditions 5, 6. At the time of far vision viewing, the portion lying above the visual angle of 30° is not used very often and the portion lying above the visual angle of 50° is out of the field of vision and accordingly the peripheral portion of the lens is not strictly required to satisfy the conditions 5, 6.

This embodiment is explained in detail with reference to the following embodiments.

Embodiment 1

Fig. 6 is a plan view of the convex refractive surface of a progressive multifocal ophthalmic lens in accordance with this invention which has two refractive surfaces facing each other at least one of which has a far zone 1, an intermediate zone 2, a near zone 3 and a principal

meridian curve M.

Fig. 7 illustrates the variation of the focal power along the principal meridian curve of the lens of Fig. 6. The focal power in the far zone lying above the point A is constantly 6.0D, that in the near zone lying below the point B is constantly 8.0D, and from A to B the focal power increases generally linearly except for the portion adjacent to each point. That is, the far zone reference focal power D1 is 6.0D and the near zone reference focal power D2 is 8.0D. Accordingly, the additional power Ad of this lens is 2.0D

In the lens of Figs. 6 and 7, the distance between the points A and B, i.e. the length L of the progressive portion, is 20mm and since the change of the focal power between the points A and B is almost linear, the maximum gradient of the focal power variation along the principal meridian curve M is about 0.10D/mm. The point A is the geometrical centre and the optical centre of the lens. Hereinafter the point A and the point B are referred to as the far zone centre and the near zone centre respectively.

In Fig. 8, curve *a* illustrates the variation of the focal power along the intersection of the refractive surface with the plane orthogonal to the principal meridian curve M in the far zone. Since the progressive ophthalmic lens of this embodiment is bilateral-symmetrical, the description is with respect to only a half of the lens. The focal power is constantly 6.0D again. Thus, by keeping the maximum value at 6.5D from the principal meridian curve M to a point 2mm apart from M and progressively increases to 6.5D at a point 25mm apart from M, and then progressively decreases to reach 6.0D, that is, by keeping the difference between *a* in Fig. 8 and the focal power along the principal meridian curve M in the far zone (the far zone reference focal power) not more than 0.5D, the astigmatism in the far zone can be maintained at not more than 0.5D. Also, the by a design in which the focal power at a point spaced from the principal meridian curve M is larger than that on the principal meridian curve M, the magnification of the lens in the lateral portions of the far zone increases to be close to the magnification in the intermediate or the near zone, and the distortion of the images through the lateral portion of the far zone is reduced. Accordingly, if the far zone is provided with an aspherical surface as described above, the characteristics of the lateral portions of the intermediate and the near zones are more improved without the characteristic of the far vision viewing being impaired, as compared with the case where the total far zone is provided with a spherical surface,

In Fig. 8, curve *b* illustrates the variation of the focal power along the intersection of the refractive surface with a plane orthogonal to the principal meridian curve M in the near zone. Similar to the far zone, the focal power is constant in a certain section. Then the focal power progressively decreases and sequentially, progressively increases in the lateral direction, finally to arrive at 6.0D which is the same as the far zone reference focal power, The focal power is made to be 7.0D at a point about 7.5mm apart from the principal meridian curve M so that the width of the region with an astigmatism not more than 1.0D (the near zone central portion) is about 15mm. Also, by a design in which the focal power at a point spaced from the principal meridian curve M is smaller than the focal power on the principal meridian curve, the magnification in the lateral portions of the near zone decreases to be close to the magnification of the intermediate or the far zone and consequently the distortion of the images through the lateral portions of the near zone is reduced.

In this embodiment of the progressive multifocal ophthalmic lens, the focal power variation along the principal meridian curve and the location of the far and the near zones are designed as explained so far, and the intermediate zone is defined as described in the U.S. Patent Application No. 327,288 (corresponding to G.B. No. 2,090,426A), by the inventors of the present invention. That is, an intermediate zone is provided such that the demarcations between the far zone and the intermediate zone and between the intermediate zone and the near zone are defined so that the vertical width of the intermediate zone increases in the direction towards the peripheral portion of the lens, and that an angle formed by a line normal to the surface on each point of the intersection of the refracive surface with an arbitrary plane parallel to the plane including the principal meridian curve changes in the same manner as the change of the focal power along the principal meridian curve.

Fig. 9 shows the distribution of the astigmatism of the lens designed as explained above. In Fig. 9, the line identified by, for example, 1.0 is a contour of the astigmatism of 1.0D. As is shown, the minimum width S of the intermediate zone central portion is about 10 mm, which is much larger than in known lenses.

Fig. 10 shows the distribution of the mean focal power of this lens. As can be understood from both Figs. 9 and 10, the maximum width W of the near zone central portion is about 15mm. Accordingly, the maximum width W is 1.5 times as large as the minimum width S. Thus, since the difference in the spaces between the contrours of the astigmatism between in the intermediate zone and in the near zone is small, the distortion of the images through the lateral portions of the point B is small and the lens is more comfortable to use.

As can be seen in Fig. 9, the contour of the astigmatism of 1.0D starting from the lower end of the refractive surface first extends upwardly generally parallel to the principal meridian curve

and then extends in a direction towards the lateral portion of the lens. Especially in the intermediate zone, the space between each contour of the astigmatism is large. Accordingly, in accordance with a progressive multifocal ophthalmic lens having the distribution of the astigmatism as above, the shaking of the images caused by, for example, the lateral rotation of the wearer's head is reduced by comparison with known progressive multifocal ophthalmic lenses (such as lenses shown by Figs. 3, 5) since the change of the astigmatism at each point on the refractive surface is small in this embodiment. In this embodiment, the fitting point is defined at the point A and the angle of rotation of the lens for the convergence is 8°. In Fig. 9, the tangent at the point A with the contour of the astigmatism of 1.0D is the line which inclines downwardly by the angle of about 20° from the horizontal line H. Considering the above condition with respect to the horizontal line when glazed, on the refractive surface above the line which inclines downwardly by about 12°, the astigmatism is no more than 1.0D at any point. In Fig. 19, the tangent at the point A with the contour of the mean focal power of 6.5D is the line inclined downwardly by about 21° from the horizontal line H. Thus, while Fig. 10 shows that the far zone lies above the horizontal line H, in view of the focal power, a region as low as 21° from the horizontal line H can be used for the far zone. If both the astigmatism and the mean focal power are taken into account, the region of the refractive surface above the line drawn downwardly by about 12° from the horizontal line H' when glazed is considered to be suitable for the far vision viewing. Consequently, in accordance with this embodiment of the progressive multifocal ophthalmic lens, a very wide, especially in the horizontal direction, and comfortable far vision can be obtained even in the lower part of the far zone. In this embodiment, the refractive surface is divided into the far zone, the intermediate zone and the near zone. However, these names for different zones are used only for the convenience in designing, and as mentioned above, the upper part of the intermediate zone may be regarded as the region suitable for the far vision viewing and the lower part of the intermediate zone may be regarded as the region suitable for the near vision viewing.

In the progressive multifocal ophthalmic lens of this embodiment, the length of the progressive portion is large and the region suitable for the near vision viewing is narrow. However, as mentioned before, the frequency to use the near zone in the progressive multifocal lens of the type to which this invention pertains is very low. Consequently, the slight defect of the near zone can be compensated for by looking at the nearby object while pushing up the glasses a little, or by using the wide progressive portion (the intermediate zone central portion) according to the situation. The characteristic of the near zone of this embodiment proved to be satisfactory in actual use.

Moreover, this embodiment of the progressive multifocal lens in accordance with this invention is demonstrated to be suitable not only for active uses but also for various other uses. That is, in general, people rarely maintain near vision viewing for a long time and so a region suitable for near vision viewing which is as wide as in this embodiment is usually enough. Furthermore, the wide progressive portion compensates for the narrowness of the region suitable for the near vision viewing. In addition, the reduced shaking and distortion of the images in accordance with this invention make the progressive multifocal ophthalmic lens far more convenient than those previously suggested.

Embodiment 2

The second embodiment of the progressive multifocal ophthalmic lens has the basic refractive surface which is the same as that of Embodiment 1 and has an additional power of 3.0D.

Figs. 11, 12, 13 illustrate the arrangement of the various zones, the variation of the focal power along the principal meridian curve M and the variations of the focal powers in the far zone and the near zone respectively. The main differences between Embodiment 2 and Embodiment 1, whose additional power is 2.0D, are that as specifically shown by Fig. 11, in Embodiment 2 the demarcation between the far zone and the intermediate zone lies closer to the far zone in the peripheral portion of the lens than in Embodiment 1 and that, as specifically shown by Fig. 13, the focal power in the horizontal direction in the near zone is designed to vary in the manner shown by the curve *b* of Fig. 13 in which the focal power arrives at 8.0D at a point about 5mm apart from the principal meridian curve M on which the focal power is 9.0D. Both of the above conditions of Embodiment 2 mean that the regions suitable for far vision viewing and near vision viewing, respectively are smaller than in Embodiment 1. Such a design is because of the fact that, if these regions are large as in Embodiment 1, the distortion and shaking of the images notably increase. As shown by the curve *a* in Fig. 12, the focal power in the horizontal direction in the far zone is constantly 6.0D from a point on the principal meridian curve M to a point about 2mm apart from the principal meridian curve M, then progressively increases to 6.5D at a point about 21mm away from the principal meridian curve M, being almost constantly 6.5D to a point about 25mm away from the principal meridian curve and progressively decreases to 6.0D again. Thus, there is a slight difference between the variation of the focal power in the horizontal direction in the far zone of Embodiment 2 and that of

Embodiment 1, which difference is provided in an attempt to reduce the distortion and the shaking of the images through the lateral portions of the intermediate zone.

Figs 14 and 15 respectively illustrate the distribution of the astigmatism and the distribution of the mean focal power of this embodiment of the progressive multifocal ophthalmic lens.

Given that the horizontal line H' when glazed is obtained by rotating the horizontal line H by an angle of 8° as in Embodiment 1, the region with an astigmatism of not more than 1.0D lies on the refractive surface above the line drawn upwardly by about 9° from the horizontal line H' when glazed, and the region with the mean focal power of not more than 6.0 ± 0.5D lies on the refractive surface above the line drawn downwardly by about 2° from the horizontal line H' when glazed. Thus, even though slightly smaller than in Embodiment 1, an excellent far vision which is large in the horizontal direction is obtained in accordance with this embodiment.

In the progressive multifocal ophthalmic lens of this embodiment, the maximum width W of the region suitable for the near vision viewing and the minimum width S of the region suitable for the intermediate vision viewing are approximately 10mm and 7mm, respectively and the maximum width W is 1.4 times as large as the minimum width S.

In Embodiment 2 as in Embodiment 1, the far vision viewing and the intermediate vision viewing are improved and the distortion and the shaking of the images are far less than in known lenses. Accordingly, the progressive multifocal ophthalmic lens of this embodiment is very suitable for use in the active activities and, moreover, is available to various other uses due to the wide progressive portion and the reduced shaking of the images.

In the above two embodiments of this invention, the focal power along the principal meridian curve above the point A and below the point B is constant. However, the focal power in these sections is not necessarily constant and a small increase or decrease (at most 0.5D) of the focal power with respect to that on the points A or B does not affect the improvements achieved by this invention. This condition is easily understood because the mean focal power of the region suitable for far vision viewing or near vision viewing is the reference focal power ± 0.5D in each zone as explained before. Also, the variation of the focal power along the principal meridian curve between the points A and B need not necessarily be linear but may be like a sine curve in which the maximum gradient of the focal power variation is less than a predetermined value. Accordingly, the variation of the focal power along the principal meridian curve as shown by Fig. 16 or Fig. 17 is also acceptable. In the progressive multifocal ophthalmic lens having the focal power variation as shown before by Fig. 7 or Fig. 12, the point A at the lowest end of the far zone and the point B at the top end of the near zone are the starting point and the terminating point of the increment of the focal power, respectively, and the same is to be said with respect to the lens having the focal power variation as shown by Fig. 16. On the other hand, in the lens having the focal power variation as shown by Fig. 17, the points A and B are the points where the gradient of the focal power increment changes. That is, the increasing rate of the focal power changes from large to small at the point A and vice versa at the point B. In either of the progressive multifocal ophthalmic lenses mentioned above, the focal powers on the points A and B are the far zone reference focal power D1 and the near zone reference focal power D2, respectively.

Figs. 18 and 10 show another variation of the progressive multifocal ophthalmic lens of this embodiment, in which the point B cannot be defined in terms of the point where the gradient of the focal power changes. In this lens, a certain point on the principal meridian curve where the astigmatism is smaller by about 0.5D than that at the lowest end of the principal meridian curve of the lens body 10 is defined to be the point B and the region below the point B is regarded to be the near zone. In this case, the near zone is rather smaller but is sufficient for the purpose of ths invention in which the near vision viewing is less significant than the far and the intermediate vision viewing.

Embodiment 3

Fig. 20 is a plan view of a refractive surface of the progressive multifocal ophthalmic lens disclosed in the European Patent Publication No. 39,497, the said lens having a far zone 1, an intermediate zone 2, a near zone 3 and a principal gazing line M.

When the line of vision is shifted from a distant object lying in front and viewed upwardly to a nearby object lying in front and viewed downwardly through the ophthalmic lens, the path of the line of vision is biased to the side of the nose due to the convergence. The locus of the path of the line of vision as above on the refractive surface is the principal gazing line, which gazing line divides the refractive surface of the lens into the nose-side segment and the temple-side segment. Though the principal gazing line corresponds to the principal meridian curve in, for example, Fig. 5, the term "the principal gazing line" is used in the following description.

The progressive multifocal ophthalmic lens disclosed in EP Publication No. 39,497 is designed so that the horizontal difference and the vertical difference in the distortion of the images through the lateral portions of the intermediate and the near zones on the nose-side and through these portions on the temple-side are less than physiological tolerance in humans (it is

said to be 0.5 prism diopter in general) in order to facilitate the fusion by both eyes to obtain the natural three dimensional vision with the progressive multifocal ophthalmic lenses divided into the two segments as mentioned above.

Fig. 21 illustrates the distortion of the images of a square grid when viewed through the progressive multifocal ophthalmic lens designed as above by both eyes, Fig. 21 being provided for explaining the difference of the distortions perceived by the right eye (solid lines) and by the left eye (broken lines).

As is apparent from Fig. 21, there is almost no difference in these distortions in the vertical direction, and the difference in the horizontal direction is small.

Fig. 22 illustrates the distribution of the astigmatism of the progressive multifocal ophthalmic lens of Fig. 20. The righthand side of Fig. 20 is the nose side and the lefthand thereof is the temple side. This lens is prescribed as a plano lens when far vision viewing and has the additional power of 2.0D. The principal gazing line shown by the broken line M is biased to the side of the nose in the near zone. The curves C1 and C2 are the demarcations between the far zone and the intermediate zone and between the intermediate zone and the near zone, respectively. Fig. 22 illustrates the astigmatism of the progressive multifocal ophthalmic lens as lens astigmatism. However, since the prescribed power of this lens is plano, Fig. 22 is regarded as illustrating the distribution of the surface astigmatism on the aspherical surface of the progressive multifocal lens. (The surface astigmatism is the difference between the maximum and the minimum surface power at a point on the curved surface of the lens: on a spherical surface, the surface astigmatism is 0 because the surface power is equal in all directions).

As shown by Fig. 22, the biasing of the principal gazing line to the side of the nose causes the astigmatism on the nose-side to be larger than that on the temple-side in the intermediate zone and in the near zone (it being especially remarkable in the intermediate zone). This is because the intermediate zone, which is the transient zone where the curved surface of the far zone must be transformed to the near zone, is narrower on the side of the nose.

In this progressive multifocal ophthalmic lens, reference is made to a region having an astigmatism of not more than 0.5D (in this region, the astigmatism is not perceived by the wearer in general and the region is hereinafter referred to as the clear viewing zone). Reference is also made to a region having an astigmatism of not more than 1.0D. (In the latter region, although the astigmatism is indeed perceived by the wearer, there is no practical problem and this region is therefore hereinafter referred to as the practical clear viewing zone. The practical viewing zone of course includes the clear viewing zone.). In this lens, the far zone belongs to the clear viewing zone except for the lateral portions adjacent to the intermediate zone and the total area of the far zone is covered by the practical clear viewing zone. In the intermediate zone, the clear viewing zone and the practical viewing zone having the minimum widths of approximately 4mm and 8mm, respectively lie centering around the principal gazing line. The near zone includes the clear viewing zone and the practical viewing zone having the maximum widths of approximately 14mm and 17mm, respectively centering around the principal gazing line. In the design of the progressive multifocal ophthalmic lens, the clear viewing zone and the practical clear viewing zone having similar characteristics and accordingly only the practical clear viewing zone is referred to in the following description.

In this progressive multifocal lens, the length of the principal gazing line belonging to the intermediate zone, that is, the length of the principal gazing line required for providing the predetermined additional power (2.0D in this case) by the increment of the focal power between the far zone and the near zone (hereinafter referred to as the length of the progressive portion) is about 15mm.

Fig. 23 shows the variation of the focal power along the principal gazing line, in which the ordinate is the position on the principal gazing line and the abscissa is the focal power. A, B are the cross points of the principal gazing line and the demarcations C1, C2, respectively. In parenthesis, the length of the progressive portion of the progressive multifocal ophthalmic lenses presently on the market is 6mm at the shortest and 16mm at the longest.

The characteristics of a third embodiment of a progressive multifocal ophthalmic lens in accordance with this invention is shown in Figs. 24 and 25.

Figs. 24 and 25 illustrate the distribution of the astigmatism and the variation of the focal power along the principal gazing line, respectively. This embodiment is regarded as plano at the time of viewing the far vision and has the additional power of 2.0D, which are the same conditions as in the before-mentioned lens according to the European Patent.

In the progressive multifocal ophthalmic lens of Embodiment 3, the length of the progressive portion is 20mm and the maximum width of the practical clear viewing zone in the near zone is 14mm. Thus Embodiment 3 is characterized by a longer progressive portion and a narrower practical clear viewing zone (clear viewing zone) in the near zone than occurs in known lenses. By designing as above, the astigmatism of the intermediate zone and the shaking of the images through the intermediate zone are greatly improved as shown by Fig. 24. To be more concrete, the width of the practical clear viewing zone in the intermediate zone lying centering around the

principal gazing line is about 11mm, which is larger than the before mentioned lens of the European Patent by 30 to 40%. Moreover, in the lateral portions outside the practical clear viewing zone in the intermediate zone, the astigmatism is remarkably reduced in relation to that of the known lens. In the lateral portions, the astigmatism increases by a substantially constant rate in the direction from the far zone to the near zone and the increase in the astigmatism between the far and the near zones is very smooth. Accordingly, a wide intermediate vision is obtained in accordance with this embodiment.

Furthermore, as shown by Fig. 25, the gradient of the focal power variation along the principal gazing line is easy, and a smooth shift from the far vision viewing to the intermediate vision viewing is realized.

Also, the distribution of the astigmatism reflects the magnitude of the shaking of the images caused by the movement of the wearer's head, because the variability of the variation in astigmatism coincides, with the variability in the variation of the distortion of the images, as shown by Fig. 21, and this variation causes the shaking of the images. In accordance with this invention, the variation in the distortion of the images through the intermediate zone is much more smooth and smaller than in known lenses, indicating that the shaking of the images is largely reduced. As explained above, in accordance with Embodiment 3, the progressive multifocal ophthalmic lens, which is very suitable for active use such as sports or shopping, is improved in the natural three dimensional vision and a wide field of intermediate vision are obtained and in that the shaking of the images caused by the movement of the wearer's head is very much reduced by designing so that the vertical and the horizontal differences in the distortions of the images between the nose side segment and the temple-side segment of the lens is less than the tolerance in humans.

Embodiment 4

Fig. 26 is a plan view of the refractive surface of the progressive multifocal ophthalmic lens disclosed in the U.S. Patent No. 3,687,528 (corresponding to G.B. 1,295,504) and its applied invention U.S. 3,910,691 (corresponding to G.B. 1,403,675).

In Fig. 26, M is an umbilical curve which is vertically extending in the general centre of the refractive surface. Though this umbilical curve M corresponds to the principal meridian curve as shown in Fig. 5, the term "umbilical curve" is used in the following description. The umbilical curve is defined as a general straight line in some lenses and is biased to the side of the nose between the optical centre of the region for viewing far vision and the optical centre of the region for viewing near vision as shown by Fig. 26 and others. The focal power of the refractive surface along the umbilical curve progressively varies between the optical center *a* of the region for viewing far vision and the optical centre *b* of the region for viewing near vision. The difference of the focal powers is referred to as the additional power.

As shown by Fig. 27, the section of the refractive surface of the progressive multifocal opthalmic lens of Fig. 26 taken along a plane orthogonal to the umbilical curve is, for a specific plane between the optical centre *a* of the region for effecting far vision and the optical centre *b* of the region for effecting near vision substantially a circle having a radius of curvature equal to the radius of curvature of the umbilical curve at the point containing the section (S2 in Fig. 27, Fig. 28(b)). For any other orthogonal plane above and below the substantially circular section, the section of the refractive surface has a radius of curvature progessively decreasing and increasing in a direction away from the umbilical curve with respect to the radius of curvature of the umbilical curve containing the section (S1 in Fig. 27, Fig. 28(a) and S3 in Fig. 27, Fig. 28(c)), respectively.

Fig. 29 illustrates the distribution of the astigmatism of a progressive multifocal ophthalmic lens designed as described above, Fig. 29 being provided for explaining the characteristics of the lens. The lens shown by Fig. 29 is for the left eye, prescribed as plano at the time of the far vision viewing, and has an additional power of 2.0D. The length of the umbilical curve between the optical centre *a* of the region for effecting far vision and the optical centre *b* of the region for effecting near vision is about 16mm. The variation of the focal power along the umbilical curve is illustrated in Fig. 30.

The structural characteristics of the progressive multifocal ophthalmic lens of this type are connected with the distribution of the astigmatism of Fig. 29 as explained below:

In the segment above the optical centre *a* of the region for effecting far vision (this segment is used for viewing distant objects and is hereinafter referred to as the far zone), the astigmatism increases in the direction away from the umbilical curve. Similarly, in the segment below the optical centre *b* of the region for effecting near vision (this segment is used for viewing nearby objects and is hereinafter referred to as the near zone), the astigmatism increases in the direction away from the umbilical curve. In the segment below the optical centre *a* of the region for effecting far vision and above the optical centre *b* of the region for effecting near vision (this segment is used for viewing intermediate objects and is hereinafter referred to as the intermediate zone), the contours of the astigmatism embody gentle "hillocks" on both sides of

the umbilical curve. The variation of the astigmatism from the far zone through the intermediate zone to the near zone is progressive and smooth.

By distributing the astigmatism widely and making the variation thereof smooth as mentioned above and hence by preventing the abrupt distortion of the lens, the shaking of the images caused by the movement of the wearer's head which is one of the major defects of progressive multifocal ophthalmic lenses is largely reduced in accordance with the above patents.

Fig. 31 illustrates the distribution of the astigmatism of the fourth embodiment of the progressive multifocal ophthalmic lens in accordance with this invention. The lens of Fig. 31 is for the left eye, presecribed as plano, at the time of far vision viewing and has the additional power of 2.0D as the lens explained above.

Fig. 32 illustrates the variation of the focal power along the umbilical curve of the lens of Fig. 31.

In this embodiment, the length of the umbilical curve between the optical centre *a* of the region for effecting far vision and the optical centre *b* of the region for effecting near vision (hereinafter referred to as the length of the progressive portion) is 20mm. The variation of the focal power along the umbilical curve in the progressive portion is almost linear except for the adjacent portions of the optical centres of the regions for effecting far and near vision, respectively.

As is apparent from Fig. 31, the difference of the astigmatism more abruptly increases in the lateral portions of the near zone than in the lenses of the U.S. Patents described before. In order to be more concrete, reference is made to the region having astigmatism of not more than 0.5D (in this region, the astigmatism is generally not perceived by the wearer and is hereinafter referred to as the clear viewing zone) and the region having an astigmatism of not more than 1.0D (generally, in this region, although the astigmatism is indeed perceived by the wearer, there are no practical problems and this region is hereinafter referred to as the practical clear viewing zone). In the near zone, the maximum widths of the clear viewing zone and of the practical clear viewing zone are approximately 9mm and 14 mm, respectively, which are about 20% less than the widths of about 12mm and 17mm, respectively in the known lens.

Embodiment 4 of this invention is thus characterised by a longer progressive portion and a narrower practical clear viewing zone (as well as of the clear viewing zone) than occurs in known lenses.

In accordance with this embodiment, the field of vision of the far zone and of the intermediate zone, and the shaking of the images, are improved in the following way:

As Fig. 31 shows, in the far zone, the astigmatism is small in the lateral portions and a wide, excellent field of vision with little blurring is obtained, while in the intermediate zone the astigmatism is notably reduced and the minimum width of the practical clear viewing zone is about 9.5mm, which is about 60% larger than that of the known lenses (about 6mm). The "hillocks" of the astigmatism in the lateral portions of the intermediate zone are gentler than those of the known lenses, indicating decreased distortion in these portions. Consequently, the shaking of the images is further reduced in comparison with the known lenses.

As mentioned before, the practical clear viewing zone in the near zone in this embodiment is narrower than in the known lenses. However, since the practical significance of the near zone is less than the far and the intermediate zone in this invention, such a condition of the near zone as above is acceptable.

As described so far, in accordance with this embodiment, the shaking of the images is far better than in the lenses disclosed in the before-mentioned U.S. Patents. Furthermore, the progressive multifocal ophthalmic lens in accordance with this embodiment has an expanded field of vision through the intermediate zone and is very suitable for active use such as sports or shopping.

Embodiment 5

Figs. 33 and 34 respectively illustrate the distortion of the images of a square grid when viewed through the progressive multifocal ophthalmic lens disclosed in U.S. Patent No. 4,056,311 (corresponding to G.B. 1,484,382), and the distribution of the astigmatism of the same lens. The lens of Figs. 33 and 34 has an additional power of 2.0D, and has a progressive portion as long as 16mm. Figs. 33 and 34 correspond to only the left half of the lens because the lens is bilateral-symmetrical and the right half is omitted.

In this example, substantially the whole surface of the far zone (the zone above the point A) is provided with a spherical surface, and the near zone (the zone below the point B) also includes a wide portion which is provided with a substantially spherical surface. In the lateral portions (the portions outside lines Q) in the intermediate and the near zones, the principal axes of the principal curvatures at each point lie in the horizontal and the vertical directions. As a result, as shown by Fig. 33, the horizontal lines and the vertical lines of the square grid are perceived to be horizontal and vertical through the portions outside the lines Q and there is no skew distortion of the images.

On the contrary, in the portion inside the lines Q, there are portions through which the images are considerably distorted. Also, as shown by Fig. 34, the astigmatism is concentrated at these portions, leading to severe blurring of the images. Accordingly, in the intermediate zone, the region adjacent to the principal meridian curve where the astigmatism is small and desirable vision is obtained (the clear viewing zone and the practical clear viewing zone) is very narrow, and the intermediate vision viewing is uncomfortable to use.

Fig. 35 is a plan view of the refractive surface of the fifth embodiment of the progressive multifocal ophthalmic lens in which this invention is applied to the lens disclosed in the above-mentioned U.S. Patent No. 4,056,311.

In this embodiment, the additional power is 2.0D, the length of the progressive portion is 20mm and the focal power along the principal meridian curve in the progressive portion varies linearly. The maximum width of the region with an astigmatism of not more than 1.0D in the near zone is 14mm.

Figs. 36 and 37 respectively illustrate the distortion of the images of a square grid when viewed through the progressive multifocal ophthalmic lens of this embodiment and the distribution of the astigmatism of the same lens for the left half of the lens only.

As is apparent from both drawings, the considerable distortion of the images through the portion inside the line Q1 (or Q2 in the right half) which is present in the prior art is reduced and the concentration of the astigmatism in this portion is also reduced. Thus, intermediate vision viewing is greatly improved in accordance with this embodiment.

Accordingly, an object of this invention, namely to provide a progressive multifocal ophthalmic lens in which a wide field of far vision is obtained and the shaking of the images is reduced, is fully attained.

As explained in detail with reference to embodiments described above, by designing the progressive multifocal ophthalmic lens so that the length of the progressive portion is much larger than the gradient of the focal power variation is gentler than in known lenses, wide fields of intermediate vision and of far vision are provided and the distortion and shaking of the images through the lateral portions of the lens are substantially reduced in accordance with this invention.

Moreover, by narrowing the region suitable for near vision viewing by comparison with known lenses, wide fields of vision of generally the same width are obtained in the area from the intermediate zone to the near zone, consequently largely reducing the distortion and the shaking of the images through the lateral portions of the lens.

Thus, in accordance with this invention, a progressive multifocal ophthalmic lens is obtained which is improved in that the fields of the far vision and the intermediate vision are expanded and the distortion and shaking of the images are very small, when compared with known lenses.

Accordingly, a progressive multifocal ophthalmic lens in accordance with this invention is very suitable for active uses such as sports like golf, driving a car, walking during shopping and so on and is fully acceptable as a progressive multifocal lens for a number of other purposes.

CLAIMS

1. A progressive multifocal ophthalmic lens comprising two refractive surfaces facing each other;

at least one of said two refractive surfaces further comprising a far vision viewing zone for viewing mainly distant objects and a near vision viewing zone for viewing mainly nearby objects at the top and the bottom of said one refractive surface, respectively, and an intermediate vision viewing zone for viewing mainly intermediate objects between said two zones;

said intermediate vision viewing zone having an intermediate vision viewing zone central portion and said near vision viewing zone having a near vision viewing zone central portion;

at least one of said two refractive surfaces having a principal meridian curve extending vertically in the general centre of said far, intermediate and near vision viewing zones;

the surface power along said principal meridian curve in said intermediate vision viewing zone progressively increasing from a far vision viewing zone reference focal power (D1 diopters) to a near vision viewing zone reference focal power (D2 diopters);

the additional power Ad ($Ad = D2 - D1$) of said at least one of said two refractive surface being 1.5 diopters or more,

said intermediate vision viewing zone central portion and said near vision viewing zone central portion extending on left and right sides of said principal meridian curve;

given that the principal curvatures at each arbitrary point on said refractive surface are C1 and C2, each point on said refractive surface in said intermediate vision viewing zone central portion satisfying the condition;

$$|C1 - C2| \leqq 1/(N-1)\ (m^{-1}),$$

and each point on said refractive surface in said near vision viewing zone central portion

satisfying the conditions;

$$|C1 - C2| \leqq 1/(N-1)\ (m^{-1})$$

$$\frac{D_2 - 0.5}{N-1} \leqq \frac{C1 + C2}{2} \leqq \frac{D_2 + 0.5}{N-1}\ (m^{-1})$$

where N is the refractive index of the lens material;

given that the minimum width of said intermediate vision viewing zone central portion and the maximum width of said near vision viewing zone central portion are S(mm) and W(mm), respectively,

said minimum width S, and said maximum width W satisfy the conditions;

$$W \leqq 30/A\ (mm)$$
$$W \leqq 1.5 \times S\ (mm)$$

where A is the value of the additional power Ad expressed in units of diopters;

and given that the gradient of the variation of the surface power at each arbitrary point along said principal meridian curve is G (diopter/mm),

every point along said principal meridian curve in said intermediate vision viewing zone satisfies the condition;

$$G \leqq Ad/18\ (diopter/mm),$$

where Ad is the additional power in units of diopters.

2. A progressive multifocal ophthalmic lens as claimed in claim 1 in which each point on said refractive surface above a straight line starting at the fitting point and drawn on both sides downwardly by an angle of substantially K degrees from the horizontal line of said lens when said lens is glazed satisfies the conditions;

$$|C1 - C2| \leqq 1/(N-1)\ (m^{-1})$$

$$\frac{D_1 - 0.5}{N-1} \leqq \frac{C1 + C2}{2} \leqq \frac{D_1 + 0.5}{N-1}\ (m^{-1})$$

where K is calculated from the formula;

$$K = 50 - A \times 20,$$

in which A is the value of the additional power Ad expressed in units of diopters.

3. A progressive multifocal ophthalmic lens as claimed in claim 1 or 2 in which the surface power along said principal meridian curve is constant in said far vision viewing zone and in said near vision viewing zone, respectively: and, in said intermediate viewing zone, the angle formed by the normal line at each point along the intersection of a plane parallel with said principal meridian curve and said refractive surface and a plane containing said principal meridian curve changes in the same manner as the change of the surface power along said principal meridian curve in said intermediate vision viewing zone.

4. A progressive multifocal ophthalmic lens as claimed in claim 3 in which the surface power along the intersection of a plane orthogonal to said principal meridian curve on said refractive surface in a direction away from said principal meridian curve, in said far vision viewing zone, is constant for a certain distance from said principal meridian curve, then progressively increases for the predetermined distance and then progressively decreases, and in said near vision viewing zone, is constant for a certain distance, then progressively decreases for the predetermined distance, and then progressively increases.

5. A progressive multifocal ophthalmic lens as claimed in claim 1 or 2 in which said refractive surface is divided into a nose-side segment and a temple-side segment by a principal gazing line extending from the far vision viewing zone to the near vision viewing zone, and in said intermediate vision viewing zone and said near vision viewing zone, the horizontal and the vertical differences in the distortion between said nose-side segment and said temple-side segment are less than the tolerance in humans.

6. A progressive multifocal ophthalmic lens as claimed in claim 1 or 2 in which said refractive surface includes an umbilical curve extending vertically in the general centre of said refractive surface, and said refractive surface further comprises a section of said refractive

surface taken along a plane orthogonal to said umbilical curve somewhere between the optical centre of the far vision viewing zone and the near vision viewing zone,

said section being of substantially circular shape with a radius of curvature having a value equal to that of the radius of curvature of said umbilical curve at the point of intersection of said umbilical curve with said section of substantially circular shape, and dividing said refractive surface into an upper portion in which sections taken along a plane orthogonal to said umbilical curve have the value of the radius of curvature decreasing in a direction away from said umbilical curve, and a lower portion in which sections thereof have the value of the radius of curvature increasing in the direction away from said umbilical curve.

7. A progressive multifocal ophthalmic lens as claimed in claim 1 or 2 in which, in a portion outside a point 20 to 25mm apart from said principal meridian curve, the principal axes of the principal curvatures at each point on said refractive surface lie in the vertical direction and the horizontal direction.

8. A progressive multifocal ophthalmic lens substantially as hereinbefore described with reference to Figs. 6 to 10, or Figs. 11 to 15, or Figs. 24–25, or Figs. 31–32, or Figs. 35–37 of the accompanying drawings.

9. Spectacles provided with progressive multifocal ophthalmic lenses as claimed in any preceding claim.

10. Any novel integer or step, or combination of integers or steps, hereinbefore described and/or shown in the accompanying drawings, irrespective or whether the present claim is within the scope of, or relates to the same or a different invention from that of, the preceding claims.

Printed in the United Kingdom for Her Majesty's Stationery Office, Dd 8818935, 1985, 4235.
Published at The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained